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MINUTES OF PROCEEDINGS
OF
THE INSTITUTION
OF
CIVIL ENGINEERS;
WITH OTHER
SELECTED AND ABSTRACTED PAPERS.

VOL. LXV.

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ERRATUM.

Vol. lxv., p. 51, line 8 from bottom, for "ultimately," read "alternately."

THE

INSTITUTION

OF

CIVIL ENGINEERS.

SESSION 1880-81.—PART III.

Sect. I.—MINUTES OF PROCEEDINGS.

1 March, 1881.

JAMES ABERNETHY, F.R.S.E., President, in the Chair.

It was announced that the Council had recently transferred to the class of

Members.

Charles James Bowstead.
William Hall.

Also that they had admitted as

Students.

Joseph Wilding Bell.
Benjamin Swinton Biram, B.A.
Richard Victor Boswell.
Robert Harold Brookhouse.
Godfrey Turnbull Elliot.
Alexander Jabez Hogg.
Frederick White Kershaw.
Patrick McGuire.
Adolphe Albert Minjoot.
Henry Edmund Punchard.
John Henry Punchard.
William Charles Punchard.
Percival Ross.
Guy Noble Taylor.
Harry Williamson Teed.
Walter Price Williams.

The following candidates were balloted for and duly elected as

Members.

Frederic Foster Bateman.
Walter Fiddes.
Edwin James Grice.
Charles Hunt.
John Houseman Hutchinson.
Augustus Hamilton Jacob, B.A.
Charles Henry Moberly.
Henry Frederick White.

Associate Members.

Henry Ogle Bell-Irving, Stud. Inst. C.E.
James Briggs, Stud. Inst. C.E.
Charles Clegg, Stud. Inst. C.E.
Thomas Adey Cox.
Leonard Creasy.
Charles Stafford Ellery.
Charles Tierney Elton.
Arthur Clement Evans.
Gilbert Henry Garrett.
Robert Hay.
William Field How, Stud. Inst. C.E.
William Jackson.
Francis Robert Johnson, Stud. Inst. C.E.
Frederick Jopling.
Edward Pillow.
Edmund Herbert Stevenson.
Fletcher Wilson Stevenson.
Sidney Evance Stevenson.

Associates.

Thomas Alexis Dash.
James Spencer Hollings.

(*Paper No. 1778.*)

"The Tide Gauge, Tidal Harmonic Analyser, and Tide Predicter."

By SIR WILLIAM THOMSON, LL.D., F.R.SS. L. and E., M. Inst. C.E.

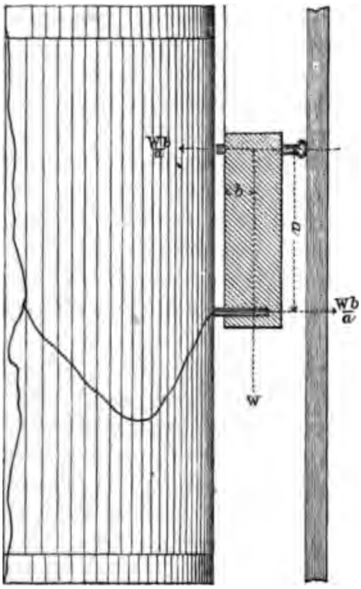
I. THE TIDE GAUGE.

THE self-registering tide gauge is a well known instrument for automatically recording, by a curve traced on paper, the height of the sea level at every instant above or below some assumed datum line. The first essential of the instrument is a floater, which rises and falls with the water. The practical annulment of wave disturbance, so that the floater at each instant may be nearly enough in the position corresponding to the mean of the water level for several minutes, is an important detail. The next thing is mechanism to cause a marking pencil to move in a straight line in simple, but much reduced, proportion to the motion of the floater. The instrument is completed by clockwork, carrying paper with a uniform motion perpendicularly across the line of motion of the pencil, with proper arrangements to cause the pencil to press with sufficient force on the paper to make its mark. An ink marker, as in the Tide Predicter, to be explained later, has been tried for tide gauges both by the Author and by others, but has hitherto been found unsuccessful, on account of the slowness of the motion, and the long time through which the action has to be continued; and as there is ample driving power in the tide gauge, there is not the strong reason that there is in the tide predicter for preferring the ink-marker to the pencil; so, for the present at all events, a pencil is by general consent the marker of an automatic tide gauge.

The Tide Gauge now to be described differs from other tide gauges only in certain dynamical and geometrical details, designed for giving, in more convenient form, results of greater, or of better assured, accuracy; with a smaller floater and finer and smaller, but not less hardy, mechanism. The leading idea for the design of every machine ought to be the work to be done by it. With this idea properly kept in view, the force in each part of the mechanism, essentially involved in the work which the machine has to do, is the force to be designed for. The strength in all the parts of the machine ought to be designed to suit the force thus calculated, and nothing more except what may be entailed by the massiveness required for the hardiness of the machine, according to the circumstances in which it is to be used. In the tide gauge, the work done is the moving of the pencil across the paper, subject to the pressure required to produce the mark. For this pressure 50 grammes weight is sufficient, and about 10 grammes may therefore be the force required to move the pencil. The motion of the pencil is made to be from one-tenth to one-hundredth of the motion of the floater, according to the place where the tide gauge is to be used. For the Mediterranean, one-tenth is a convenient scale; for Bristol, St. Malo, or the Bay of Fundy, one-fiftieth to one-hundredth would be suitable. A convenient general scale for English tide gauges is $\frac{4}{10}$ inch to the foot, or a ratio of $\frac{1}{30}$. With even the lowest ratio, say $\frac{1}{10}$, the force at the floater corresponding to 10 grammes at the pencil is only 1 gramme, and therefore, so far as merely moving the pencil is concerned, the area of the floater's water-line need not be more than 10 square centimetres to avoid any error on this account of as much as 1 millimetre above or below its correct position. But in ordinary tide gauges the frictional character of the slide is such as to entail the need for a force to move the pencil-carriage scores of times the force required to do the essential work of moving the pencil across the paper. This entails a much larger floater than need be, and heavier and more frictional mechanism all through the instrument. The Author's first object, therefore, was to minimise the friction of the pencil-carriage. Considerable progress had been made towards attaining this object in the ink-marker of the South Kensington tide predicter: and in the Author's first tide gauges, exactly the same geometrical slide was used as in this instrument. In it the motion of the marker is vertical, the axis of the paper cylinder being vertical, instead of both being horizontal, as had been the case in nearly all previous tide gauges. The marker is weighted to the amount of about 600 grammes; so as, in the Clyde or other tide gauges with ratios of motions of 1 to 30, to produce (effect of frictions of the mechanism in either direction largely allowed for) an upward pull on the floater of from 16 to 24 grammes. This pull is transmitted through a fine platinum wire, which it keeps tight enough, and which is strong enough to bear a pull of 110 grammes. The platinum wire is wound round a wheel of 6 inches diameter. The shaft of this wheel carries a pinion, working into a wheel on a second shaft. This second shaft has a fine flat grooved drum, of 3 inches diameter. On this drum is wound a wire cord, strong enough to bear 1,200 grammes, on which is hung the marker, of 600 grammes weight. Plate 1, Fig. 1, represents the design for the second of three tide-gauges erected, or to be erected, on the Clyde by the Trustees of the Clyde Navigation.

A large drawing, which is exhibited, shows the first of the tide gauges now at work, having been set in action immediately after the cessation of the frost in January. In it the marker, as in the Author's two tide predicters, and all his tide gauges hitherto made, travels vertically up and down, and is hung by a vertical bearing thread attached to it at a point between the vertical through its centre of gravity and the paper. The couple constituted by gravity downwards through its centre of gravity and the upward pull of the bearing wire, is balanced by the reaction of the paper on the marker, in a horizontal line, near the bottom of the mass, and an equilibrating horizontal force constituting the reaction of the plane front of a fixed guiding flat bar against a round-ended pin fixed to the back of the marker near the top, as shown in section in Fig. 2. Thus the equilibrium of the marker is a very simple and direct application of Poinsot's theory of the equilibrium of couples. Fig. 2 also shows an upper front pin projecting towards, but not touching, the paper. The

FIG. 2.



fixed guiding frame is completed by four upright rectangular bars, one on each side of the pencil tube and upper front pin, and one on each side of the upper back pin; these two last being joined by the flat bar already mentioned, which constitutes a back-plate for the whole frame. The five sliding points of a geometrical slide[1] are thus provided for the marker as follows:—

1. The end of the pencil tube slipping on the paper.
2. The point of contact of the round end or knob of the upper back pin on the plane surface of the back-plate.
3. The contact of this knob on one or other of the two side guide-rods.
4. The contact of the upper front pin on one or other of the two front guide-rods.
5. The contact of the pencil tube, on that one of the front guide-rods on which it is pressed by the frictional force of the paper.

The distance between the two front guide-rods is so small that even if, through any disturbance, the pencil tube is brought into contact with the other guide-rod, the corresponding error in the apparent time of the mark is insensible. This plan has worked well in the several tide gauges to which it has been hitherto applied, and in the British Association and India Office tide predicters. But the Author has now returned to a much better plan, which he tried, not resolutely enough, to realise during the course of the construction of the first tide predicter eight years ago.

It is shown in the model exhibited, and it is to be used in the second tide gauge to be made for the Trustees of the Clyde Navigation, and in the third tide predicter now nearly finished. In it the back plate and its side guards are done away with, and the requisite pressure of the pencil or ink tube on the paper is produced directly by a component of gravity perpendicular to the cylindric surface of the paper, in the line along which it is traversed by the marking point. For this purpose the axis of the cylinder is not set exactly vertical, but to an incline of 1 in 5 (angle of about $11\frac{1}{2}°$, or one-fifth of a radian) between the tangent plane through the marking point and the true vertical. This inclination gives a component of 120 grammes (being one-fifth of the whole weight of the loaded marker) perpendicular to the paper. This component is balanced by the paper at the place where it is touched by the pencil tube and the contained lead, or by the tube alone when the marking is by ink. Fig. 3 shows the equilibrium of four forces in this plane, consisting of two components of gravity (W sin *i* and W cos *i*), the normal component of the pressure of the paper on the pencil, and the tension of the bearing cord. It will be seen from the figure that the centre of gravity is intended to be in the very point of the pen or pencil. This condition is easily attained, with all needful accuracy, as follows:—Place the marker with its point resting on one side of a horizontal bar of wood, and adjust till it balances on the point; then, holding it by its bearing thread, adjust so that when the bar is inclined at any angle to the horizontal, the marker still balancing on its point, keeps the bearing thread as nearly as may be parallel to the bar, at a distance of not more than 1 or 2 millimetres from it. The centre of gravity of the loaded marker being thus adjusted to be nearly enough in the marking point of the pen or pencil, it is clear that when the marker is hung in its place in the instrument, the pen or pencil will press on the paper with a force equal to the whole of the component (W cos *i*) of the weight of the marker (W) perpendicular to the tangent plane of the cylinder at the point touched. Hence with the weight and inclination stated above, the pressure on the paper is 120 grammes, which is more than twice the amount required for marking by blacklead. The part of it used for pressing the lead on the paper is applied by means of a spring on the end of the little blacklead bar remote from the paper, and the remainder of the 120 grammes is spent in pressing the end of the marking tube on the paper.

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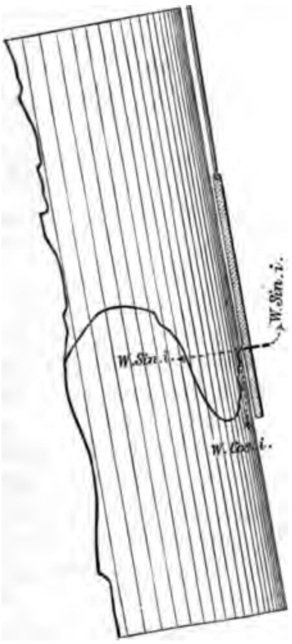
[1] *Vide* Thomson and Tait's, "Natural Philosophy," sec. 198; or "Elements of Natural Philosophy," sec. 168.

Fig. 3.



To complete the equilibrium, the component of the frictional force of the paper, pulling the pen or pencil point in the direction of the paper's motion, must be balanced. This is done by a directly opposing force—the pressure of a guide-rod—pressing against the wing of the marker, at a point in the tangent plane through the marking point, 6 centimetres from it in the horizontal line of the paper's motion, on the side towards which the paper moves.

A second guide-rod is fixed symmetrically on the other side, and the two wings of the marker are quite symmetrical. Thus, if it is desired to turn the paper cylinder, sometimes in one direction and sometimes in the other, the marker works undisturbedly, experiencing just an infinitesimal motion to annul the pressure on one wing, and give the requisite pressure on the other wing when the motion is reversed. The fulfilment of this condition is valuable in the tide predicter, though not so in the tide gauge; but independently of it, the symmetrical form is simpler and more easily made than any other. The two guide-rods serve to keep the marker in a convenient position—very near its true working position—when at any time the paper cylinder is removed for fresh paper. The model constructed for No. 2 Clyde gauge (Plate 1, Fig. 1), shows these details already realised.

This plan is a great improvement on the one described as hitherto used in the tide gauges, and in the two tide predicters already completed, which essentially involves a sum of normal pressures equal to double the pressure on the marking point, and is besides much less simple and less easily constructed.

The sum of normal pressures of the marker on pen and guide-rod in the newly-finished plan, about 135 grammes in all, may produce at most about 30 grammes of resisting frictional force against the upward and downward motion of the marker. This, with the ratio one-thirtieth adopted in the Clyde tide gauges, would give alternate augmentations and diminutions of the pull of the platinum wire on the floater to the extent of a gramme, which is but a small contribution to the ample allowance of ± 4 grammes made above for variation of amount of pull on the floater by friction in all parts of the mechanism. A specimen of the floater used in the first Clyde gauges, and for other tide gauges made by Mr. White, which have already been sent to Australia, Italy, and Madeira, is exhibited. The area of the water-line in the floater, which is a circle of 6 centimetres diameter, is about 28 square centimetres, and therefore the supposed extreme vertical disturbing force of ± 4 grammes would disturb its position by no more than $\frac{1}{7}$ centimetre, which is insensible. A much smaller floater might have been taken; the actual size was chosen for the sake of hardiness, so that no slight obstruction should check its motion up and down with the water-level in the tube, and yet its weight be small enough for safety in case of accidental stoppage. Its weight, being only 35 grammes, is less than one-fifth of the breaking weight of the platinum wire attached to it. Thus if the motion of the wire wheel of the tide gauge is stopped while the water-level is still sinking, or if at any time it be turned so as to lift the floater, the platinum wire will not be broken. This floater is of thin sheet copper. Those to be made for Nos. 2 and 3 Clyde gauges are to be of greenheart, and of the shape and size of the specimen exhibited, which weighs 56 grammes. This wood sinks in water, and an upward pull is thus required to keep it afloat. In the actual specimen a pull of 4 grammes suffices to just prevent it from sinking, and it floats well with the standard upward pull of 20 grammes. The difference between the smallest pull of 4 grammes and the greatest, 56, which it can give to the wire, constitutes an ample margin for working the wheelwork and marker of the gauge. Its property of sinking in water, unless held up, gives an important security in rendering it impossible for the wire to slack and kink when the water rises, if by any accident the motion of the wheelwork has been arrested, whether by the downward motion of the marker being stopped, or from its suspending wire being broken, or otherwise. Besides remarking that the breaking weight of the wire is 110 grammes, and that forces, whether by jerks or otherwise, which could put more of a pull on it than about 70 grammes are to be avoided, no other caution for safety is required than :—"Beware of kinks."

The Author's tide gauges have hitherto been provided with the means of using continuously a band of paper long enough to allow the curve to be traced on it simply, and without break, through the whole length required for a year. Thus, if it be not desired to take away any tracings of the machine for examination or reduction through the course of a year, no other work is necessary than to wind the clock once a week or once a fortnight, and to put in a fresh lead for the pencil as often as one is needed. The two cylinders for the paper supply and for the haul-off may, however, be omitted or left unused in any case in which it is desired to mark a week's or a fortnight's curves on a single twenty-four hours' length of paper, as has been hitherto usually done in other tide gauges. This involves the trouble of taking off a paper of curves, and putting on a fresh piece of blank paper, once a week or once a fortnight; and has the considerable disadvantage of giving a more confused appearance, and involving some practical difficulty and inconvenience in picking out the right curve for a particular day, as will be seen by looking at some of the specimens of tide-gauge work exhibited. On the other hand, the old plan has the great advantage of using less paper, and giving the results in a more compact form, and also some advantage in respect to facility of application to the Tidal Harmonic Analyser. Specimens of both the old and the new plans are exhibited (Plate 1, Figs. 4 and 5); and engineers must choose according to the circumstances which plan is to be preferred in any particular case. Whatever plan be adopted, to secure accuracy in respect both of time and datum-height, the Author uses rows of fine pins at the top and bottom of the main cylinder; with grooved rollers above and below, pressed on the paper by springs, so as to cause it to be perforated by them when the long continuous band of paper is used. By these pins the hours and half hours are indelibly marked on the paper, and the two rows which they form give two absolutely fixed datum lines, from either of which the water-level indicated by the curve may be measured. By double and triple pins the noon and midnight and six hours are distinguished from the others. In setting up the instrument it is adjusted once for all, so that the marker shall be at the desired distance from either row of pins when the water is at the desired datum-level, or at a measured distance above or below it. The paper drum is set so that the wire bearing the markers is seen to cover the corresponding time on a scale of hours divided down to five minutes, which is engraved on the upper brass rim of the drum.

When the supply and haul-off cylinders are used the haul-off cylinder, as in the first of the Clyde gauges, and in several others which have been made more or less according to this design, is actuated by a separate weight, to be wound up every time the clock is wound. This separate weight helps the main clock-weight to keep the clock going, and keeps the paper properly tight in coming away from the main drum. The Author has also used a friction gear for hauling off the paper; this is seen in the completed tide gauge made for the Author by Messrs. A. Légé and Co., of London, in 1875, which is exhibited. The Author is returning to his original plan of friction gearing for hauling off, in Nos. 2 and 3 Clyde gauges, because, with the slanting axis of the cylinders, it can now be applied with the greatest ease, so that it becomes the simplest way of managing the paper. The simplest of all would be to let the paper haul-off be the sole driving weight for the clockwork, which can be done with great ease, and unobjectionably with respect to any dynamical conditions to be fulfilled; but this simplest plan has the disadvantage, that it *requires* the long continuous band of paper, and incapacitates a tide gauge in which it is applied, from being used to give a number of days' curves on the same piece of paper, according to the old plan. On this account, therefore, for future tide gauges (if any) in which the long continuous band of paper is to be used, a new and simplified friction haul-off is to be made, according to the following description:—The upper end of the shaft of the haul-off drum is not held in position by an ordinary all-round bearing, but simply by a fork, and is so placed that the upper rim of the haul-off drum bears against the upper rim of the supply drum. The supply drum is mounted on ordinary bearings, as fine and frictionless as may be consistent with ample hardiness. The rim of the supply drum and of the haul-off drum are of one size; but the core of the supply drum is considerably smaller than the core of the haul-off drum; so much smaller that the circumference of the core of the haul-off drum with no paper on it is larger than the circumference of a year's supply of paper on the supply drum. Thus, even in commencing, the paper would be hauled off quicker than it was supplied, and therefore torn, were the wheels geared together, and therefore the paper will be tightened by the frictional pull till slipping commences. Supposing the haul-off drum to be pivoted close under its lower end, the pressure of its rim against the rim of the supply drum will, with the assumed slope of 1 in 5, amount to a tenth of the weight of the drum and whatever paper may be on it. The corresponding tangential friction between the dry brass rims will give a force very convenient in amount for hauling off the paper from the supply-drum and winding it firmly on the haul-off drum.

II.—The Tidal Harmonic Analyser.

The object of this machine is to substitute brass for brain in the great mechanical labour of calculating the elementary constituents of the whole tidal rise and fall, according to the harmonic analysis inaugurated for the tides by a Committee of the British Association appointed for this purpose in 1867, and carried on from year to year till 1876, with the aid of grants of money from the British Association and the Royal Society, and recently adopted by the Government of India. The machine consists of an application of Professor James Thomson's Disk-Globe-and-Cylinder Integrator to the evaluation of the integrals required for the harmonic analysis. The principle of the machine and the essential details are fully described and explained in Papers communicated by Professor James Thomson and the Author to the Royal Society, in 1876 and 1878, and published in the Proceedings for those years,[1] and reprinted, with a Postscript dated April 1879, in Thomson and Tait's "Natural Philosophy," 2nd Edition,

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[1] *Vide* vol. xxiv., p. 262, and vol. xxvii., p. 371.

Appendix B. It remains now to describe and explain the actual machine referred to in the last of these communications, which is the only Tidal Harmonic Analyser hitherto made. It may be mentioned, however, in passing, that the same instrument, with the simpler construction wanted for the simpler harmonic analysis of ordinary meteorological phenomena, has been constructed for the Meteorological Committee, and is now regularly at work at their office, harmonically analysing the results of meteorological observations, under the superintendence of Mr. R. H. Scott.

Figs. 6 and 7, Plate 1, represent the Tidal Harmonic Analyser, constructed under the Author's direction, with the assistance of a grant from the Government Grant Fund of the Royal Society. The eleven cranks of this instrument are allotted as follows :—

Cranks.	Object.	Distinguishing Letter.	Speed.
1 and 2	To find the mean lunar semi-diurnal tide . .	M	$2\ (\gamma-\sigma)$
3 „ 4	„ mean solar „ „ . .	S	$2\ (\gamma-\eta)$
5 „ 6	„ luni-solar declinational diurnal tide	K_1	γ
7 „ 8	„ slower lunar „ „	O	$(\gamma-2\ \sigma)$
9 „ 10	„ slower solar „ „	P	$(\gamma-2\ \eta)$
11	„ mean water level	A_0	..

The two cranks of each of the five pairs are fixed at right angles to one another on one shaft. The speeds of revolution of the five shafts are in simple proportions to the speeds of the respective tidal constituents (S, M, K_1, O, P,) which they serve to extract from the given compound result of observation. To give to each crank shaft its proper speed, the Author applied in this first machine an intermediate or "idle shaft," because he was under the impression that the required accuracy could only so be conveniently obtained in practice. He thought that the numbers of teeth in the wheels to give good enough approximations to the true speeds would be inconveniently great without the mechanical complexity of four idle shafts carrying the eight toothed wheels upon them.

Application was made to Mr. Edward Roberts, of the Nautical Almanac office, who had shown much ability in performing the arithmetical work of the British Association Committee, to find convenient factors of numbers expressing the ratio of the speeds of the four shafts M, K_1, O, P, to that of the mean solar shaft (S).

He kindly took the thing in hand and found the following solution, which the Author received in a letter dated October 27th, 1878:—

Mean solar 12 hours : mean lunar 12 hours : : 184 × 256 : 199 × 245 } M
(199 × 245) . . . . }
Mean solar 12 hours : sidereal 24 hours : : 119 × 317 : 209 × 360 . K_1
12 solar hours : 24 hours of ideal star O : : 58 × 92 : 89 × 129 . O
12 solar hours : 24 hours of ideal star P : : 178 × 221 : 242 × 326 . P

The following Table shows how very close an approximation to absolute truth is given by these numbers:—

SPEEDS of the SEVERAL TIDAL CONSTITUENTS in DEGREES per HOUR.

—	Numerical Approximation.	True Speeds.	Differences.
M	$30° \times \frac{184 \times 256}{199 \times 245} = 28°{\cdot}9841042$	28°·9841042	0·0000000
K_1	$30° \times \frac{119 \times 317}{209 \times 360} = 15°{\cdot}0410686$	15°·0410686	0·0000000
O	$30° \times \frac{58 \times 92}{89 \times 129} = 13°{\cdot}9430363$	13°·9430356	0·0000007
P	$30° \times \frac{178 \times 221}{242 \times 326} = 14°{\cdot}9589312$	14°·9589314	0·0000002

Thus it will be seen that Mr. Roberts' figures give the speeds for two of the constituents correct to the 7th decimal of a degree; and in the other two the larger difference, that for O is scarcely more than $\frac{1}{1.500.000}$ of a degree per hour. An error of $\frac{1}{1.500.000}$ of a degree per hour would only amount to one degree in about one hundred and sixty years, so that the approximations may be taken as practically perfect.

The Author afterwards found, in designing the No. 3 Tide Predicter, that his supposition of need for two pairs of toothed wheels to get the true speed for each shaft nearly enough for practical purposes was a mistake, and that all the needful accuracy is readily obtainable by a single pair of toothed wheels for each speed. The numbers of the wheels in the four pairs of wheels thus required will, for the analyser, be given in the description of the No. 3 Tide Predicter.

No. 2 Tidal Harmonic Analyser, whenever it comes to be made, will not be allowed any idle shafts. It will have four toothed wheels on the main shaft, of period twelve solar hours, and four separate crank shafts, carrying one toothed wheel, driven by one of the toothed wheels of the main shaft. It is probable that in No. 2 machine, with this great simplification, at least three more crank shafts will be allowed, so as to include the lunar six-hourly and three-hourly "overtides" or "shallow-water tides" (M_4, M_6), and the luni-solar shallow-water tide (M S) of approximately six-hour period (the harmonic mean of six lunar hours and six solar hours). The toothed gearing for two of these three proposed additional shafts (M_4, M_6) is, of course, very simple; the ratios to be dealt with being 2 to 1 and 3 to 1 (or 3 to 2), as in the meteorological analyser. All this, however, is prospective. It need only be further remarked now, that the first extension beyond the scope of No. 1 machine, in the way of constituents to be analysed for, ought to include the shallow-water tides, because they are of great practical importance, and they cannot be estimated theoretically in any case, and can only be determined by accurate observation and a rigorous analysis of the results; while the whole series of the astronomical constituents N, L, K (semi-diurnal), λ, ν, μ, S, T, R, can each be estimated with all needful accuracy for practical purposes from the analysed values of S and M, by judgment, enlightened by examination of the corresponding results of the analysis already performed by the British Association and by the Indian Government, and to be found in the British Association Reports;[1] and in the Tide Tables for the Indian ports, published by authority of the Secretary of State for India in Council.

Returning to No. 1 Tidal Harmonic Analyser (Plate 1, Figs. 6 and 7), the actual machine (which is about 20 feet long) is now in a room in the University of Glasgow, where, unhappily idle, it waits for hands to work it. Mr. Capello has kindly communicated a series of tidal curves for Lisbon; and Loanda, on the west coast of Africa, lat. 8° 48′ S., long. 13° 8′ E.: which the Author hopes soon to be able to analyse by passing through the machine.

The general arrangement of the several parts may be seen from Figs. 6 and 7. The large circle at the back, near the centre, is merely a counter to count the days, months, and years for four years, being the leap year period. It is driven by a worm carried on an intermediate shaft, with a toothed wheel geared on another on the solar shaft. In front of the centre is the paper drum, which is on the solar shaft, and goes round in the period corresponding to twelve mean solar hours. On the extreme left, the first pair of disks, with globes and cylinders, and crank shafts with cranks at right angles between them, driving their two cross-heads, corresponds to the K_1, or luni-solar diurnal tide. The next pair of disk-globe-and-cylinders corresponds to M, or the mean lunar semi-diurnal tide, the chief of all the tides. The next pair lie on the two sides of the main shaft carrying the paper drum, and correspond to S, the mean solar semi-diurnal tide. The first pair on the right correspond to O, or the lunar diurnal tide. The second pair on the right correspond to P, the solar diurnal tide. The last disk on the extreme right is simply Professor James Thomson's disk-globe-and-cylinder integrator, applied to measure the area of the curve as it passes through the machine.

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[1] *Vide* Reports, 1868, 1870, 1871, 1872, 1876.

The idle shafts for the M and the O tides are seen in front respectively on the left and right of the centre. The two other longer idle shafts for the K and the P tides are behind, and therefore not seen. That for the P tide serves also for the simple integrator on the extreme right.

The large hollow square brass bar, stretching from end to end along the top of the instrument, and carrying the eleven forks rigidly attached to it, projecting downwards, is moved to and fro through the requisite range by a rack and pinion, worked by a handle and crank in front above the paper cylinder, a little to the right of its centre. Each of these eleven forks moves one of the eleven globes of the eleven disk-globe-and-cylinder integrators of which the machine is composed. The other handle and crank in front, lower down and a little to the left of the centre, drives by a worm, at a conveniently slow speed, the solar shaft and through it, and the four idle shafts, the four other tidal shafts.

To work the machine the operator turns with his left hand the driving crank, and with his right hand the tracing crank, by which the fork-bar is moved. His left hand he turns always in one direction, and at as nearly constant a speed as is convenient to allow his right hand, alternately in contrary directions, to trace exactly with the steel pointer the tidal curve on the paper, which is carried across the line of to-and-fro motion of the pointer by the revolution of the paper drum, of which the speed is in simple proportion to the speed of the operator's left hand.

The eleven little counters of the cylinders in front of the disks are to be set each at zero at the commencement of an operation, and to be read off from time to time during the operation, so as to give the value of the eleven integrals for as many particular values of the time as it is desired to have them.

A first working model harmonic analyser, which served for model and for the meteorological analyser, now at work in the Meteorological Office, is exhibited. It has five disk-globe-and-cylinders, and shafting geared for the ratio 1 : 2. Thus it serves to determine, from the deviation curve, the celebrated "A B C D E" of the "Admiralty Compass Manual," that is to say, the coefficients in the harmonic expression

$$A + B \sin \theta + C \cos \theta + D \sin 2 \theta + E \cos 2 \theta,$$

for the deviation of the compass in an iron ship.

III. The Tide Predicter.

After having worked for six years at the Tidal Harmonic Analysis, the Author designed an instrument for performing the mechanical work of adding together the heights (positive or negative) above the mean level, due to the several simple harmonic constituents, determined by the analysis, from observations or from the curves of a self-recording tide gauge for any particular port, so to predict for the same port for future years, not merely the times of high and low water, but the position of the water-level at any instant of any day of the year. To produce a single simple harmonic motion is one of the best known elementary problems of mechanism, as indicated in the following passage of Thomson and Tait's "Natural Philosophy," (1st ed. 1867, p. 37, or 2nd ed. 1879, p. 39), sec. 55,[1] "Those common kinds of mechanism for producing rectilineal from circular motion, or *vice versâ*, in which a crank, moving in a circle, works in a straight slot belonging to a body which can only move in a straight line, fulfil strictly the definition of a simple harmonic motion in the part of which the motion is rectilineal, if the motion of the rotating part is uniform."

There are many known ways of combining two or more motions in the same or in parallel lines by levers and otherwise. The number of separate motions to be combined made it, however, not easy to see any very acceptable details for the application of levers to produce the combination which the Author desired for the Tide Predicter. On his way to attend the British Association in 1872, with Mr. Tower for a fellow-passenger, the Author was deeply engaged in trying to find a practical solution for the problem. Having shown his plans and attempts to Mr. Tower, whose great inventiveness is well known, Mr. Tower suggested, "Why not use Wheatstone's plan of the chain passing round a number of pulleys, as in his alphabetic telegraph instrument?" This proved the very thing wanted. The plan was completed on the spot; with a fine steel hair-spring, or wire, instead of the chain which was obviously too frictional for the tide predicter. Everything but the precise mode of combining the several simple harmonic motions had, in fact, been settled long before. At the Brighton Meeting, in presenting the Report of the Tidal Committee to Section A, the Author described minutely the tide-predicting machine thus completed in idea, and obtained the sanction of the Tidal Committee to spend part of the funds then granted to it on the construction of mechanism to realise the design for tidal investigation by the British Association.

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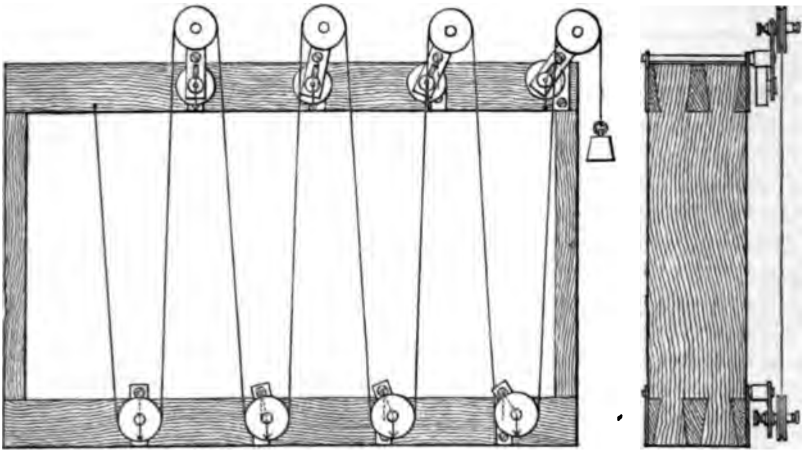
[1] Or "Elements of Natural Philosophy," by the same authors, sec. 72.

Before the end of the meeting he wrote from Brighton to Mr. White at Glasgow, ordering the construction of a model to help in the designing of the finished mechanism for the projected machine (Fig. 8). The instrument, which is exhibited, has eight pulleys on cranks, and a cord, passing over and under them alternately, is fixed at one end, and carries a weight representing the marker at the other. The Author will have to return to it presently to explain one part of the original design, the counterpoising, which he did not succeed in having carried out in the first working Tide Predicter;—this instrument belonging to the South Kensington Museum.

FIG. 8.



First Model for Tide Predicter. Scale ¼ real size.

The following statement, taken from the third edition of the "Catalogue of the Special Loan Collection of Scientific Apparatus at the South Kensington Museum, 1876," page 11, describes the general object of the tide predicter, and some of the details of the first instrument, exhibited here this evening by the permission of the authorities of the Science and Art Department, under whose care it has been permanently placed by the British Association.

"The object is to predict the tides for any port for which the tidal constituents have been found by the harmonic analysis from tide-gauge observations: not merely to predict the times and heights of high water, but the depth of water at any and every instant, showing it by a continuous curve, for a year, or for any number of years in advance.

"This object requires the summation of the simple harmonic functions representing the several tidal constituents to be taken into account, which is performed by the machine in the following manner:—For each tidal constituent to be taken into account the machine has a shaft, with an overhanging crank, which carries a pulley pivoted on a parallel axis adjustable to a greater or less distance from the shaft's axis, according to the greater or less range of the particular tidal constituent for the different ports for which the machine is to be used. The several shafts, with their axes all parallel, are geared together so that their periods are to a sufficient degree of approximation proportional to the periods of the tidal constituents. The crank on each shaft can be turned round on the shaft and clamped in any position; thus it is set to the proper position for the epoch of the particular tide which it is to produce. The axes of the several shafts are horizontal, and their vertical planes are at successive distances one from another, each equal to the diameter of one of the pulleys (the diameters of these being equal). The shafts are in two rows, an upper and a lower, and the grooves of the pulleys are all in one plane perpendicular to their axes. Suppose, now, the axes of the pulleys to be set each at zero distance from the axis of its shaft, and let a fine wire or chain, with one end hanging down and carrying a weight, pass alternately over and under the pulleys in order, and vertically upwards or downwards (according as the number of pulleys is even or odd) from the last pulley to a fixed point. The weight is to be properly guided for vertical motion by a geometrical slide. Turn the machine now, and the wire will remain undisturbed, with all its free parts vertical, and the hanging weight unmoved. But now set the axis of any one of the pulleys to a distance $\frac{1}{2}$ T from its shaft's axis, and turn the machine. If the distance of this pulley from the two on each side of it in the other row is a considerable multiple of $\frac{1}{2}\,T$, the hanging weight will now (if the machine is turned uniformly) move up and down with a simple harmonic motion of amplitude (or semi-range) equal to T, in the period of its shaft. If, next, a second pulley is displaced to a distance $\frac{1}{2}\,T'$, a third to a distance $\frac{1}{2}\,T''$, and so on, the hanging weight will now perform a complex harmonic motion equal to the sum of the several harmonic motions, each in its proper period which would be produced separately by the displacements $\frac{1}{2}\,T$, $\frac{1}{2}\,T'$, $\frac{1}{2}\,T''$. Thus, if the machine was made on a large scale, with $T, T' \ldots$ equal respectively to the actual semi-ranges of the several constituent tides, and if it is turned round slowly (by clockwork, for example), so that each shaft goes once round in the actual period of the tide which it represents, the hanging weight would rise and fall exactly with the water-level as affected by the whole tidal action. This, of course, could be of no use, and is only suggested by way of illustration. The actual machine is made of such magnitude that it can be set to give a motion to the hanging weight equal to the actual motion of the water-level reduced to any convenient scale; and provided the whole range does not exceed about 30 centimetres, the geometrical error due to the deviation from perfect parallelism in the successive free parts of the wire is not so great as to be practically objectionable. . . . . In the actual machine there are ten shafts, which, taken in order from the hanging weight, give respectively the following tidal constituents:—

1. The mean lunar semi-diurnal	M
2. The mean solar semi-diurnal	S
3. The larger elliptic semi-diurnal	
4. The luni-solar diurnal declinational	K_1
5. The lunar diurnal declinational	O
6. The luni-solar semi-diurnal declinational	K_2
7. The smaller elliptic semi-diurnal	
8. The solar diurnal declinational	P
9. The lunar quarter-diurnal, or first shallow-water overtide of mean lunar semi-diurnal	M_2
10. The luni-solar quarter diurnal, shallow-water tide . .	MS

"The hanging weight consists of an ink-bottle with a glass tubular pen, which marks the tide level in a continuous curve on a long band of paper moved horizontally across the line of motion of the pen, by a vertical cylinder geared to the revolving shafts of the machine. One of the five sliding points of the geometrical slide is the point of the pen sliding on the paper stretched on the cylinder, and the couple formed by the normal pressure on this point, and on another of the five, which is about 4 centimetres above its level and 1½ centimetre from the paper, balances the couple due to gravity of the ink-bottle and the vertical component of the pull of the bearing wire, which is in a line about a millimetre or two farther from the paper than that in which the centre of gravity moves. Thus is ensured, notwithstanding small inequalities of the paper, a pressure of the pen on the paper very approximately constant, and as small as is desired.

"Hour marks are made on the curve by a small horizontal movement of the ink-bottle's lateral guides, made once an hour; a somewhat greater movement, giving a deeper notch, to mark the noon of every day.

"The machine may be turned so rapidly as to run off a year's tides for any port in about four hours..

* * * * * * *

"The general plan of the screw gearing for the motions of the different shafts is due to Mr. Légé, the maker of the machine. The construction has been superintended throughout by Mr. Roberts, and to him is due the whole arithmetical design of the gearing to give with sufficient approximation the proper periods to the several shafts."

Specimens of the working of this machine, executed by Mr. Roberts for the undermentioned places, for which, in his work for the British Association Tidal Committee, and for the Author, he had calculated the harmonic analysis, are exhibited: Ramsgate, Liverpool, West Hartlepool, Portland, San Francisco, Cat Island, San Diego, Fort Clinch, Beechy Island, Malta, Brest, Mauritius, Port Leopold. Most of them were drawn by Mr. Roberts for sending with the instrument to the Paris Exhibition of 1878.

It was intended that each crank should carry an adjustable counterpoise, to be adjusted so that when the crank is not vertical the pulls of the approximately vertical portions of wire acting on it through the pulley which it carries shall, as exactly as may be, balance on the axis of the shaft, and that the motion of the shaft shall be resisted by a slight weight hanging on a thread wrapped once round it and attached at its other end to a fixed point. This part of the design, planned to secure against "lost time" or "back-lash" in the gearings of the shafts, and to preserve uniformity of pressures between teeth and teeth, teeth and screws, and ends of axles and "end-plates," was not carried out, but can easily be applied to the machine now exhibited.

The way to realise the counterpoising specified in the preceding statement is shown in the original wooden model (Fig. 8). Each pulley with its central stud is equal to twice the weight of the marker hung on one end of the wire. The slotted crank arm of each shaft of the lower row is permanently balanced by a counterpoise rigidly connected with it in its prolongation on the other end of the shaft (this obvious counterpoise is not executed in the model). Each pulley of the upper row is overcounterpoised by an adjustable counterpoise to such a degree that if the shafts were all loosed from the gearing so as to be each free to turn round its axis, every one of them would rest in any position. Thus any one of them may be turned round its axis into any position and it rests there. This condition is clearly not vitiated by shifting out or in the stud of any of the pulleys of the lower row in its slot; but if any of the pulleys of the upper row be shifted its counterpoise must also be shifted a corresponding distance out or in on the other side.

It will be seen that the plan of this first tide predicter involves a great simplification in attaching the bearings of each pulley direct to its crank arm, in a proper position adjustable to be either at the centre, in which case its contribution to the resultant motion will be zero, or at any distance from the centre to correspond to the range of the harmonic constituent which it is to represent, instead of having a crank-pin adjustable to different distances from the centre, and causing this crank-pin to produce simple harmonic motion in the manner described in Thomson and Tait's "Natural Philosophy." Thus the more obvious plan has the advantage of imparting simple harmonic motion to the centre of each pulley. On the other hand the simpler plan gives circular motion to the centre of each pulley, which is equivalent to simple harmonic vertical motion compounded with an equally simple harmonic horizontal motion. The deviation from verticality which the horizontal motion gives to the straight intermediate parts of the thread is a derogation from perfect accuracy in the desired composition of simple harmonic motions, and is a serious drawback to be weighed against the advantage of its great simplicity of mechanism. The model produced, which was made in the winter of 1872–73 for the Tidal Committee of the British Association, by Mr. Légé, under the superintendence of Mr. Roberts, and which was exhibited at the Bradford Meeting of the Association, shows the composition of two simple harmonic motions on the rigorous plan. The Author did not, however, for the first working instrument to be made for the British Association, venture on the great expenditure which would have been required to carry out the rigorous plan for a sufficient number of tidal constituents to be practically useful, even with all the improvements anticipated in the way of proper geometrical and dynamical designs for the slide, and vertical motion for the marker; and the simple plan of the original wooden model was adhered to, which was accordingly realised in the British Association Tide Predicter.

The second Tide Predicter was made by the Indian Government for the purpose of predicting the tides for the Indian ports, for which, in consequence of the large diurnal tides, the ordinary plan of tide-tables, showing the time and height of high water on the days of full and change, or on every day of the year, does not afford information enough for practical purposes. A design by Mr. Roberts and Mr. Légé was submitted for the Author's approval, involving the true simple harmonic motions for the centres of the pulleys instead of the circular motions of the first machine. This modification, though making the instrument less simple, was rendered in fact necessary by the large range which it was proposed to give for the resultant curve, and which would have required inconveniently great lengths for the straight parts of wire between the upper and lower rows of pulleys to nearly enough annul the geometrical error of the simpler plan. The Author approved generally of the plan, and recommended to the India Office that it should be carried out by Mr. Légé as maker, under the superintendence of Mr. Roberts. The details of the slides had not been laid before him in the first instance; and after some progress had been made, Mr. Roberts proposed instead of slides to introduce for converting circular into rectilineal motion a system of link-work, of which the suggestion had come from France in some of the numerous pieces of ingenious mechanism which followed the celebrated "Peaucellier's cell" in rapid succession. The Author pointed out that the simplest mechanism sufficed, and that no advantage could be gained by abandoning the elementary slide; and as a suggestion towards details he sent a working drawing of the slide which he had then designed for his harmonic analyser (Plate 1, Figs. 6 and 7). In other respects the India Office machine was a repetition of the British Association tide predicter, with twice as many tidal constituents, greatly improved arithmetical exactness in respect to the periods of the several shafts, and on an enlarged scale. In it, as in the British Association instrument, the number of teeth in the toothed wheels was calculated by Mr. Roberts.

For the India Office instrument the Author gave the same principle of counterpoising as that of the original wooden model, but carried out, not by counterpoises fixed oppositely to the crank-arms on the shafts, but by cords passing vertically upwards from the slides over fixed pulleys, and stretched by proper weights hung on their other ends. The condition to be fulfilled is the same, being that, if each shaft was loosed from its gearing and left free to turn without friction, it would remain in whatever position it was placed. The precise way to carry out this condition will be described with No. 3 Tide Predicter, now nearly finished.

The same general plan of gearing as that devised by Mr. Légé for the first tide predicter was also adopted in the second instrument. The motions are transmitted from a main driving shaft by intermediate shafts bearing endless screws, to toothed wheels on the tidal constituent shafts. In thinking of the mechanism to give the proper speeds to the several shafts, it did not occur to the Author till he began to design practical details for the harmonic analyser, after the tide predicter for the Indian Government was more than half finished, that the simpler plan of merely toothed wheels, gearing into one another, was preferable to any use of intermediate shafts with endless screws. Besides the great unnecessary complication which it gives to the machine, the method by endless screws involves the practical disadvantage that speed is got up very high and run down again between the driving and the driven shafts. Thus, in the India Office machine, when working at such a rate as to trace a year's curves in four hours, some of the wheels and screws turn at from 1,100 to 1,600 revolutions per minute. In the British Association tide predicter the high speed of the intermediate screw-shafts had not been noticed as a fault, because the mode of marking time on the curve in that instrument had limited the speed of working to something less than the greatest speed that, so far as wheel-work was concerned, could have been easily attained. But the jigging motion of the ink-bottle for marking time had been discarded from his tide gauges before the India Office tide predicter was designed, and never entered into the design of this instrument; and he was disappointed to find that its rate of working was limited to one year per four hours through the great speed that this required in the screw-shafts.

To move the ink-bottle marker up and down through the range of the semi-diurnal tide in two seconds is a very moderate speed of working, and this would produce a year's curve in twenty-four minutes. But this is just ten times the speed to which the method of mechanism chosen limits the practical working of the India Office instrument.

The Author has therefore designed and nearly made a third Tide

Predicter, in which there is no getting up of speed and running down again, and the proper speeds for the several tidal shafts are obtained by the simple and obvious method of toothed wheels. It is even unnecessary to have the intermediate idle shafts of the harmonic analyser, and thus in the new tide predicter there is only one main shaft carrying eleven toothed wheels; and separate tidal shafts, each carrying one toothed wheel, gearing into one of the wheels on the main shaft except in four instances (M_4, M_6, K_2, M S), in each of which the toothed wheel on the tidal shaft gears into another toothed wheel on another of the tidal shafts. A complete plan of the whole gearing between the main shaft and the tidal shafts is shown in Fig. 9, with the numbers of teeth on each wheel worked, and with pins projecting from the wheel or one of the wheels on each tidal shaft to indicate a crank-pin with its distinguishing letter according to the British Association schedule of tidal constituents.

The following Table shows how close an approximation to astronomical accuracy is given by the numbers chosen for the teeth of the several wheels. These numbers the Author found by the ordinary arithmetical process of converging fractions.

Tidal Constituents.	Speeds in Degrees per Mean Solar Hour.		Losses of Angle in Machine	
	Accurate.	As given by Machine.	Per Mean Solar Hour.	Per Half Year.
M_2	28°·9841042	$15\times\frac{485}{251} = 28^\circ{\cdot}9840630$	+0°·0000412	0°·180
K_1	15°·0410686	$15\times\frac{366}{365} = 15^\circ{\cdot}0410959$	−0°·0000267	0°·117
O	13°·9430356	$15\times\frac{343}{369} = 13^\circ{\cdot}9430894$	−0°·0000538	0°·237
P	14°·9589314	$15\times\frac{364}{365} = 14^\circ{\cdot}9589040$	+0°·0000242	0°·119
N	28°·4397296	$15\times\frac{802}{423} = 28^\circ{\cdot}4397163$	+0°·0000133	0°·059
L	29°·5284788	$15\times\frac{313}{159} = 29^\circ{\cdot}5283018$	+0°·000177	0°·78
ν	28°·5125830	$15\times\frac{230}{121} = 28^\circ{\cdot}5123966$	+0°·0001864	0°·82
M S	58°·9841042	$15\times\frac{230}{121}\times\frac{271}{131} = 58^\circ{\cdot}9836600$	+0°·000444	1°·95
μ	27°·9682084	$15\times\frac{468}{251} = 27^\circ{\cdot}9681275$	+0°·0000809	0°·36
λ	29°·4556254	$15\times\frac{487}{248} = 29^\circ{\cdot}4556451$	−0°·0000197	0°·087
Q	13°·3986609	$15\times\frac{410}{459} = 13^\circ{\cdot}3986928$	−0°·0000318	0°·14

The main shaft goes once round in the period corresponding to twenty-four solar hours, and a crank-pin, marked S_1, is supplied to allow the meteorological tide of that period to be taken into account in the tide prediction for any port for which it has been found to exist in sufficient amount to be of practical importance. Each of the other fifteen shafts carries a crank-arm and pin, giving simple harmonic motion to the centre of one of the pulleys by means of a crosshead and slide, as shown in Fig. 10, which represents the instrument in the stage up to which it is already completed, and in which the whole working of the composition of fifteen simple harmonic motions is in action, pulling up and letting down a weight, which in the completed instrument will be replaced by an ink-bottle. The cylinder for carrying the paper has not yet been made, and is therefore not shown in the drawing.

In this machine there is no idle shaft; every shaft carries a crank contributing to the general result, and the greatest speed of any one is that of M_6, corresponding to a revolution in four mean lunar hours.

The several slides, pulley-frames, and pulleys in the upper row are not all of the same weight, those for the small tidal constituents being lighter. Those of the lower row corresponding to the smaller constituents are weighted so as to be of the same weight as those for the larger constituents. The weight of each slide, with attached pulley-frame and pulley of the lower row, is about 60 grammes. This weight is exactly borne by the two straight portions of wire passing upward from the pulley (in vertical lines at equal distances on its two sides from its centre of gravity), and the weight of the ink-bottle marker is therefore to be made exactly equal to half this amount. Each slide, pulley-frame, and pulley of the upper row is pulled downward by the same amount (60 grammes), by the two straight portions of wire passing downward on each side. Hence the counterpoise is made to exactly balance this amount added to the weight of its own pulley, pulley-frame, and slide. Thus if the crank-pins were removed, and the slides and pulleys left perfectly free, with the ink-marker on one end, and the other end fixed, all are in equilibrium. Hence, if the machine turn infinitely slowly, the pressure on the guides is zero, and the pressure to be provided for in the actual motion is just what is needed to balance the couple constituted by the upward or downward pressure of the crank-pin in its slot, and the reaction against acceleration of the slide pulley-frame and pulley (and of the counterpoise and its revolving pulley in the case of the upper row of tidal pulleys) which is in a vertical through the centre of inertia of the whole.

In working at as slow a rate as one turn of the main shaft per four seconds (or one year's curves in twenty-four minutes) the reactions against acceleration in all parts of the machine are so small as to be scarcely perceptible in the main mechanism, however slight it may be made. A form and arrangement of guides and sliding pieces has therefore been chosen, which admits of the moving parts being very much lighter and less frictional than those of the harmonic analyser, or of the second tide predicter. Some details of the plan are shown in Fig. 11. The wire, fixed at one end, passed over and under the pulleys, and carrying the 30-gramme ink-bottle, is steel, of No. 50 B. W. G., weighing $\frac{1}{30}$ gramme per metre. Its whole length is 300 centimetres. Its elongation by a difference of pull of 1 gramme is $\frac{1}{40}$ millimetre: and it is strong enough to bear a weight of 500 grammes, or over fifteen times the weight of the ink-bottle.

The Paper is illustrated by several models and diagrams, from which Plate 1 and the woodcuts have been prepared.

Discussion.

Sir William Thomson.

Sir WILLIAM THOMSON commenced with an explanation of the models and drawings. He showed a model constructed to aid in the design for No. 2 Clyde tide gauge, in which was a pencil-marker on the second of the two plans described in the Paper and represented in Plate 1, Fig. 1. The cylinder carrying the paper was inclined to the vertical, and looked like the "leaning tower of Pisa." The cylinder could be taken off and re-applied in a moment. The bearing plate was slightly cupped, so that the weight of the cylinder pressed entirely on its rim. The spike in the centre bore no part of the weight; it was merely a guide to keep the cylinder in the middle. The cylinder was adapted either for a long roll of paper or for marking a week's or a fortnight's curve on one paper. It had been almost determined in the case of the Clyde tide gauges that instead of a very long slip of paper for a year's curves, the curve of a week or perhaps a fortnight should be traced on one piece of paper. There would be little trouble and no difficulty in the affair. The person who wound up the clock would carry the cylinder away and substitute another with paper properly placed on it. Or if he could be trusted to put on fresh paper, there would be a table in the tide-gauge house with papers ready ruled with the time and the datum lines. All that would be necessary was to lay the cylinder in the proper position and roll it over the paper so as, by aid of the hour-pins on the cylinder, to wind the paper upon it, and then fix it by two little adhesive overlaps. Referring to the geometrical slides of the two plans, and to the general principle of a geometrical slide, Sir W. Thomson remarked that good workmanship was too often put in requisition to overcome evils of a bad design. A good design in many cases required no fitting; and where it was possible it was better to manage with no fitting; for the finest fitting might be undone by a little warp in the material or by a piece of grit. In the pen- or pencil-markers exhibited there might be an inequality in the paper projecting as much as $\frac{1}{8}$ inch, but, if not too steep, it would not disturb the marker, which would be pressed out, and simply slip over it. He would test the instrument by shaking it roughly, and it would be seen that there was no error in the marking. With regard to the floater, he had a greenheart one shown in action. It weighed 50 grammes, and was a little heavier than water. Greenheart took kindly to the water, but india-

Sir William Thomson.

rubber or gutta-percha, slightly weighted with metal, would do very well. Something was wanted which would just sink—not with too much force. If the motion of the wheelwork became arrested—if the pencil broke down or was caught in the paper—when the tide rose, the wire would become slack and therefore be liable to kink if the floater floated without any upward pull from the wire. The great safeguard was to beware of kinks. In fact the sinking floater might be called an anti-kink arrangement. In case of any arrested action of the wheelwork, the floater would sink, and keep the wire tight. The early specimen alluded to in the Paper, made by Mr. Légé for the Author, was exhibited. In all the tide gauges since made for the Author a very light flat-rimmed wheel was substituted for that in the specimen, which was too heavy, and spirally grooved. There was no occasion for the grooves, because the height of riding of the thin platinum wire in the groove was infinitesimal in its effect on the reckoning of the water-level; so that the riding of the wire was not a thing to be avoided. A tide gauge should always when possible be placed vertically over the vertical sea-tube. In cases in which this was not judged practicable, as in the tide gauge recently placed on the Admiralty pier, at Dover, a stouter wire, a larger floater, and a counterpoise besides the ink-bottle were necessary. Otherwise the simple arrangement was one shaft for the main wheel on which the wire was wound, and a second shaft carrying a drum on which the wire bearing the pencil was wound; then, when the tide rose, the pencil went down, and when the tide fell, the pencil went up. Thus in a tide-gauge curve on its drum in the instrument the high water was down, and the lower water up; the hours must therefore be marked from right to left, and the turning must be in the direction of the hands of a watch, so that when the paper was taken off and turned to make high water up and low water down, the part corresponding to past time would be to the left, and future to the right. In all the tide gauges he had made hitherto, he had used a long slip of paper. The long slip extending round the room contained a year's curve for Mauritius, drawn by Mr. Roberts, by means of the South Kensington Tide Calculating Machine. At the rate of a foot a day the length of paper would be 365 feet. With seven curves on one paper the sum of the lengths would only be 52 feet. Fourteen curves would probably be a more convenient number to put upon one paper. He held in his hand a paper with thirty curves, drawn by a self-recording tide-gauge at Loanda (West Coast of Africa), and it would be seen

Sir William Thomson. that the appearance was very confusing. That number was too great, but he did not think that a fortnight's curves on one paper of twenty-four hours' length would be too much. He was certainly a convert to putting several curves on one paper. The Dover tide-curves, which he was able to exhibit through the kindness of Mr. Druce, M. Inst. C.E., the harbour-engineer, were very interesting. It would be seen that the line was much thickened. There were oscillations of 2 or 3 feet in the tide gauge which had been recently put up there under the direction of Mr. Druce, who had informed him that in all other respects its working was satisfactory. Mr. Légé was now making a copper guard tube, in order to remedy that evil. It was to extend 6 feet below low-water mark, ending in a small hole about ¼ inch in diameter, so that it would be impossible for any pumping up and down to take place. If in two or three minutes the water rose by several inches, or even half a foot, the floater would show it. A rising and falling by wave-disturbance in five or ten seconds would not affect the floater to any sensible degree. Thus the quick oscillation up and down would be annulled, and he had no doubt that the tide gauge would be in a perfectly satisfactory state.

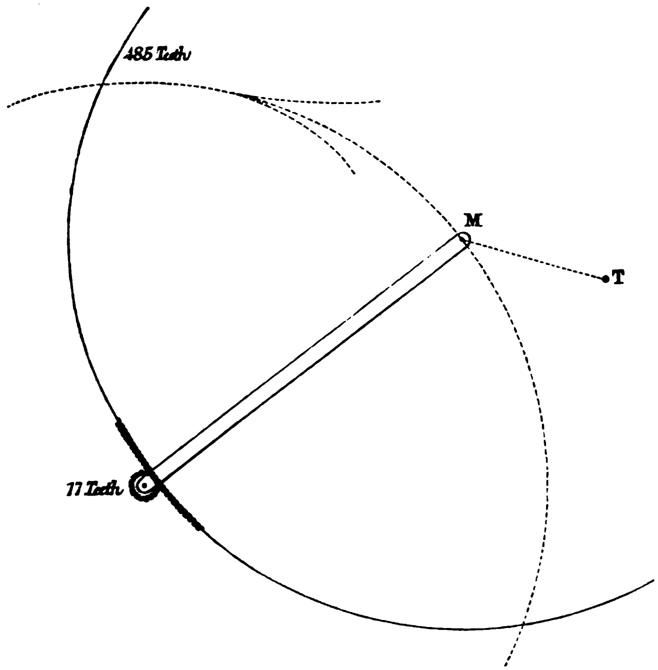
With regard to the Tidal Harmonic Analyser, he had a rough model to exhibit. One of the twenty-four hours' tidal curves, or a paper containing seven or fourteen, was placed on the cylinder, which went round once in twelve hours. The circumference of the cylinder was half the twenty-four hours' length of the paper. The two ends of the paper were united, and it ran round (like an endless towel on a roller) when the cylinder was turned. The instrument had been explained in the paper, and he would only show the management of it. To move the pointer along to the right and left in tracing the curve he had to turn a little crank with his right hand alternately to right and to left. The left hand was always kept turning one way; the right hand alternately one way and the other. The manipulation might appear to be very puzzling, but he was informed that at the Meteorological Office the instrument worked satisfactorily, and that the manipulation became easy after a little practice. It would be seen that the disk oscillated alternately in one direction and the other, and caused the counter to turn alternately forwards and backwards if the centre of the globe remained in one position. But if, while that change of direction of motion of the disk took place, the globe was turned over to the other side by the motion of the fork bar, then the counter kept turning in one direction, and thus each of the eleven counters counted out

Sir Will
Thomso

the amount of one particular harmonic constituent of the complex variation represented by the curve presented for analysis.

With regard to the Tide Predicter he wished to explain an epicyclic mechanism for the combining of two simple harmonic motions, which he had described at a meeting of the British Association at Brighton in 1872, and was the simplest possible way of producing and of combining two harmonic constituents, though essentially inapplicable to more than two. Fig. 12 represented a pinion fixed on the end of a stud. The large circle represented a wheel about twenty-eight and a half times the diameter of the pinion. There were seventeen teeth in the pinion, and four hundred and eighty-five in the wheel. Imagine first a fixed framework, the pinion rotating in one direction, and the wheel rotating in the opposite direction. The angular velocities of the wheel and pinion would be as 485 to 17. Take now the whole machine and turn it round the axis of the pinion with an angular velocity equal to the pinion's but in the contrary direction; that annulled the angular velocity of the pinion, and added the amount to the first-supposed angular velocity of the wheel;

Fig. 12.



Sir William Thomson. making the angular velocity of the wheel 485 + 17, or 502, if 485 be called the angular velocity with which the bearing of the wheel was carried round. Now the "speeds" of the mean solar and mean lunar semi-diurnal tides were as 502 to 485, very exactly. (See M_2 in the Table of Speeds in Part III. of the Paper.) Thus, by a crank-pin T, carried by the wheel in this mechanism, a solar tide was superimposed on a lunar tide. The point T (Fig. 12) changed its level according to the resultant effect of the mean lunar semi-diurnal tide and the mean solar semi-diurnal tide. The semi-range of the first of these tides was the radius of the circle described by the wheel; the semi-range of the second was the distance of the point T from the centre of the wheel.[1] This epicyclic method was a mechanical realisation of the construction in kinematics corresponding to the "polygon of forces" well known in elementary statics, for the case of two constituents; and it was a very useful as well as simple method when there were only two to be combined.

With regard to the particular mode of combining the motion which he adopted, by a hair-spring passing under and over pulleys:—as stated in the Paper, Mr. Tower had made the suggestion to him in a railway journey from Portsmouth to Brighton, at the commencement of the meeting of the British Association in 1872. Before the end of the meeting he wrote to Mr. White, and gave him instructions, and before the end of the month he wrote to Mr. Roberts, and told him that he had given instructions, for the construction of the wooden model now exhibited. Mr. Roberts had been with him, before the meeting of the British Association, for a few days, assisting to complete the report of the Tidal Committee for the meeting of the Association. During that time he continued discussions that he had had with Mr. Tower on the subject of his projected tide-predicting machine: and in the course of these discussions Mr. Tower made several suggestions, and amongst them a suggestion as to floaters in tubes, according to which, on hydrostatic principle, the effect could be summed up. Pushing in one piston caused water to rise in a tube; pushing in another added its effect; pulling out another caused a corresponding subtraction from the whole; and so on, with any number of pistons. With that beautiful idea it could be seen how the combination might be realised without mechanism. That was a very interesting suggestion of Mr. Tower's inventive mind; but he did not himself regard it as a convenient

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[1] A working model was exhibited at the meeting of the 15th of March. See conclusion of the Discussion.—W. T.

Sir Willi Thomson

practical solution of the problem, nor did Sir W. Thomson. Mr. Roberts wrote to him: "I like Mr. Tower's idea of floaters as well as any of the different things that have been contemplated; but at present I cannot see a good method of combination." In reply Sir W. Thomson commented thus, in a letter to Mr. Roberts despatched before the end of August 1872: "The floats would not work well. He (Mr. Tower) suggested also a plan with pulleys and a cord or chain which led me to a very simple plan with a long hair spring round pulleys centered on cranks. I have given White instructions to commence a partial model for trial." The result of those instructions was the wooden eight-component model (Fig. 8) now before the meeting. It had only yesterday come to his knowledge that in the report in the *Athenæum* of the meeting of the British Association at Bradford in 1873, the Tide Predicter had been described as "Mr. Roberts' instrument." The origin of that misapprehension had been explained by Mr. Roberts, in a letter to the Author of date October 23, 1873, informing him that a label describing the instrument as of his (Mr. Roberts') design had been affixed to the instrument by mistake during his absence. No doubt the reporter had taken his information from the false label. When the machine was exhibited at Paris in 1878, in charge of Mr. Légé, under direction of Mr. Roberts, it was designated as Sir William Thomson's Tide-calculating Machine, and was accompanied with a description, extracted from the catalogue of the loan collection of South Kensington, which contained the following: "The general plan of the screw gearing for the motions of the different shafts is due to Mr. Légé, the maker of the machine. The construction has been superintended throughout by Mr. Roberts, and to him is due the whole arithmetical design of the gearing to give with sufficient approximation the proper periods to the several shafts." Mr. Roberts' and Mr. Légé's translation of that passage (giving less credit to Mr. Roberts) was, "Tous les nombres ont été donnés par Mr. Roberts." He should not have troubled the members with such a statement, but that he wished to make it clear that he had dealt in a perfectly fair manner with those who had worked for him on the tide-predicting machine.

Mr. Robe

Mr. E. Roberts, of the Nautical Almanac Office, remarked, with regard to the Author's tide gauge, that in the "Philosophical Transactions" for 1838,[1] there was a description of Mr. T. G. Bunt's tide gauge, erected in 1837 in front of the

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[1] *Vide* p. 249.

r. Roberts. Hotwell House at Bristol. An abridged description of it was also given in the article on Tides and Waves in the "Encyclopædia Metropolitana," by the present Astronomer Royal.[1] The instrument had a recording pencil with vertical guides, a vertical recording barrel divided round its upper and lower edges to time, float wire and wood float. Great care was bestowed on the pencil suspension and guides. The instrument recorded accurately, and was at work from the time of its erection until dismounted in the course of the improvements in the river Avon about 1872. The tide gauge was, he believed, still preserved in the dock-engineer's office. Various materials were successively tried for the float line, including wire, silk, and fish-line. The material that answered the purpose best was silk saturated with a mackintosh varnish. The platinum wire of the Author's tide gauge had been found to be acted upon prejudicially, and to break into small pieces after being some time in use. Fine gilt copper wire also, as used on the tide gauge at Dover, required renewal every few weeks.

With respect to the Tidal Harmonic Analyser, the outcome of Professor James Thomson's Disc-Globe-and-Cylinder Integrator, he could not agree with the Author's statement that the whole series of declinational, parallactic and other perturbational lunar and solar semi-diurnal tides could be estimated with all needful accuracy for practical purposes. The total omission also of all long-period tides, both in the completed machine and also in that projected, was a serious defect, as it was impossible to estimate those tides, depending as they did so much on local and meteorological circumstances. The accuracy of the results obtained by the machine would largely depend on the precision with which the mechanism had been made. The globes should be perfect spheres, the disk a true plane, and the recording cylinder truly turned, balanced, and accurately centred. The homogeneity of the metal spheres would also enter as an element in the accuracy of its working. If the metal was not homogeneous and free from air cells, the sphere would fail to respond to the motion of its fork-guide, and the proper effect would not be communicated to the brass cylinder.

The manipulator also must very carefully follow the course of the curve with the tracing style, which must be kept true to time, otherwise inaccuracies would be introduced in the results which could not be eliminated. He thought the slow motion screws of the record-barrel and the tracing style could be omitted with advantage. A hand-rest would be sufficient for the tracing style,

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[1] *Vide* vol. v., p. 364 (473).

Mr. Roberts.

and a fair speed could be given to the record-barrel by a pulley and weight. Sufficient resistance to the record-barrel could be applied by the finger should it turn too fast for those portions of the curve not easily followed by the tracing style. A stop pin would arrest the motion when desired. This arrangement would allow greater freedom to the manipulator.

An instrument made to include the twenty to thirty tidal constituents usually evaluated, if not arranged with parallel bars or in other ways, and on the same scale as the Author's, would be of the very undesirable length of at least 100 feet.

In order, however, to test the accuracy of the working of the complete analyser, he should be pleased if, after the Author had passed the series of Spanish and African tides through the machine, he might be permitted to analyse the same curves numerically. A comparison of the results would afford a practical test of the efficacy of the instrument.

It was necessary, with regard to the Tide Predicter, that Mr. Roberts should enter somewhat into detail, as he considered the Author's version of his share in the production conveyed a very inaccurate idea of the real facts of the case. He was present on board the Author's yacht in August, 1872, when Mr. Beauchamp Tower suggested, among possible methods of combination, that of the chain and pulleys. He was also present a few days after in Section A of the British Association at Brighton, when the Author gave a description of a projected Tide Predicter. Sir W. Thomson was, however, he believed, in error in stating that it was Mr. Tower's chain-and-pulley method of combination that he there described. Mr. Roberts well recollected the plan which the Author sketched out and illustrated by a drawing on the black board, and which was an extension of an epicyclic method of combination, already carried out to a limited extent in a tidal clock then just completed, and afterwards shown before the close of the Brighton meeting. Mr. Tower, who was also present, afterwards told Mr. Roberts how much simpler he considered his own plan than the one described by the Author of the present Paper. The following account, extracted from the *Athenæum* of the 31st of August, 1872, bore on this point:—

"Sir W. Thomson went on to describe a tidal watch which was being constructed, and which he hoped to exhibit in a few days. It would indicate the height of the water, so far as dependent on the sum of the principal lunar tide and the principal solar tide, and would be adjustable for the amplitudes of these two tides at different places. There was an additional provision for

Roberts. showing the time of high water. Very similar in principle to this watch is a calculating machine, which Sir William is planning fo tidal computations. Each elementary tide gives a height of wate proportional to the height of the end of a clock hand, whic makes one revolution with uniform speed during the period of th elementary tide. If the end of this hand carries another clock the hand of this clock will be at a height corresponding to th sum of two elementary tides. It is proposed in this way t produce a movement which shall represent the sum of all th sensible constituents of the total tide, and to make the machin self-recording by a curve which it will trace on paper."

A still further confirmation of this was given later on. Th Author stated that "Before the end of the meeting he wrote fro Brighton to Mr. White at Glasgow, ordering the construction of model to help in the designing of the finished mechanism for th projected machine," Fig. 8. Mr. Tower's plan, however, if taken u appeared to have been quickly abandoned by the Author, for the end of the following November, Mr. Roberts received a descri tion of a new machine which the Author intended having mad by Mr. White. It was intended for two purposes, "one to serve as cheap tide indicator, and another to serve as a constituent in t tide-calculating machine to be made," and was thus describe "a new machine . . . . will have the solar hand on a fixed axl and the lunar hand connected with it by a fixed pinion, worki on a movable wheel and pinion, and a movable pinion working on second wheel, which is to carry a second hand, and give it a slo retrograde motion relatively to the solar hand." Thinking fro this description that the Author had abandoned Mr. Tower's ide Mr. Roberts, unknown to the Author, gave Mr. Légé (a mechanici specially recommended for the purpose), in February 1873, dir tions to construct the two-component model now exhibited, on M Tower's suggested plan, and fitted on the rigorous method of co bining two simple harmonic motions by means of parallel slid This model was completed, as now shown, about May 1873, and was then seen for the first time by the Author, who accompani Mr. Roberts to Mr. Légé's workshop to inspect it. It was a seen shortly afterwards, amongst others, by Professor Guth Mr. Bottomley, and by the late Mr. Froude. It was upon t model that the British Association ten-component machine w planned, with certain alterations by the Author, who was chairm of the Tide Committee. The chief alterations were the substi tion of an ink-recorder in place of the pencil, the change of pl of the instrument to one nearly vertical, the omission of the sli

Mr. Robert

the centering of the pulleys on the cranks, and the consequent reduction of the length of the recording barrel to lessen the geometrical error introduced by the non-parallelism of the chain. The machine thus sketched in idea in June 1873, was completed during the Author's absence from England, under Mr. Roberts' direction, and exhibited in September 1873, at the Bradford Meeting of the British Association. The following extract was from the *Athenæum* of the 4th of October, 1873:—

"Mr. Roberts' machine, which was exhibited in connexion with the Report of the Tidal Committee, traces a curve which is the resultant of no less than ten harmonic motions in parallel directions. It has been constructed out of the funds of the Tidal Committee, for the purpose of tracing a perpetual succession of tidal curves for any particular port. The period-ratios of the ten motions are put into the machine once for all by permanent gearing, and correspond to the period-ratios of certain elements of the sun and moon with respect to the earth. The ten amplitudes are adjustable to suit any particular place, but are permanent for that place. The pen which traces the curve hangs at one end of a fine steel chain, which passes alternately above and below ten pulleys corresponding to the ten harmonic motions, the other end of the chain being fixed, and the centre of each pulley describes a circle whose radius represents amplitude. The machine is driven by turning a handle, and the amount of chain hauled in or paid out during any part of the motion is equal to the sum of the rises and falls or falls and rises of the upper and lower pulleys respectively. The machine is an improvement upon a very different plan, which was suggested by Sir William Thomson at last year's meeting." Some additions and alterations were subsequently made. An improved suspension was made to the recording pen, which allowed the instrument to be strictly vertical, a disk with projecting cams was fitted to the solar component, to give time indications by producing a short horizontal movement of the pen, and on the suggestion of Mr. Légé, continuous paper was adopted for the record.

With regard to the Tide Predicter which Mr. Roberts had made for the Indian Government, it would only be necessary to refer to his Paper upon it in the Proceedings of the Royal Society, read on the 19th of June, 1879. He might here, however, state that he submitted that Paper, before being read, to Sir W. Thomson, by whom it was absolutely approved. In it he had given credit to the Author for the improved parallel slide, and also to Mr. Légé for the plan of the wheel gearing. No progress, Mr. Roberts. however, had been made with the machine when Mr. Roberts received the drawing of the slide from the Author in March, 1878, as he did not receive the official authorization from the Indian Government to plan and construct the machine until the following May. Mr. Roberts alone was responsible for the construction of the instrument, and was free to employ whomever he pleased to make the mechanism. A full and illustrated description of it would be found in the *Engineer* of the 19th December, 1879. The Author's objection to the limit of speed of working of the India Office predicter was not a valid one; the machine, being automatic, could be set over night, the traced curves being ready for manipulation the next morning. He had found, however, that even with this machine it could be driven at a greater speed than would allow a true and unbroken curve to be traced on the recording barrel, and he doubted much if the Author's projected machine could be run to trace a whole year's curves in twenty-four minutes, unless a very short abscissa was given to the curves, and a short barrel again used for the delineations. He could not regard the choice of less accurate ratios in the Author's contemplated machine as an improvement in design, seeing that the machine was one to produce as accurately as possible the best attainable results. Even allowing this derogation from possible accuracy, the numbers of the teeth in some of the wheels were very large. For instance, one of the wheels for the N component had eight hundred and two teeth. Allowing only a pitch of 1½ millimetre for the pitch of the teeth of the bevel wheels, this number would give a diameter of 15 inches, a size extremely difficult to make with the lightness and hardiness desired by the Author. It was a curious fact with regard not only to Mr. Roberts' two-component model, but also to both the completed Tide Predicters, that they were all not actually seen by the Author before completion and in thorough working order.

In conclusion, he was exceedingly pleased that in the Author's projected predicter, he had again reverted to Mr. Roberts' original plan of slides, which were mounted on the first model and in the more finished predicter which he had made for the Indian Government.

Mr. Roberts took this opportunity to announce that the Government of India were most anxious that as much use as possible might be made of their Tide Predicter, and he was authorized to use it on payment of a nominal fee for the predictions of the tides for any place, whether for the purposes of navigation or the manifold wants of harbour engineers.

Mr. Deaco

Mr. G. F. **Deacon** said the points upon which he desired to offer a few remarks were very minor ones. As more than five hundred recording instruments of different kinds had been constructed according to his designs, he had had some experience in the matter of the pens and pencils employed for the automatic registration. He had been delighted to hear that this small but most important subject had received attention from the Author of the Paper. The principles which Sir William Thomson advocated had been, in a modified degree, applied in many of the instruments to which he had referred. In the instrument before him, for example, the construction of the pencil-carriage was such that the point of the pencil was almost exactly in the vertical line passing through the centre of gravity of the carriage; and the wire upon which the carriage hung was exactly in that vertical line. The pencil was a metallic one, and the pressure was produced by a constant weight acting upon it through the agency of a lever. Two forces tended to press the carriage out of the vertical line of its supporting wire; first the normal pressure of paper against the pencil, second, the friction of the paper against the pencil tending to move it in the direction of rotation of the drum. The first was balanced, as already stated, by a weight at the end of a short lever, the reaction of which was balanced by two small rollers bearing against vertical guides; its amount was about 20 grammes or 1 oz., showing that the metallic pencil and prepared paper were in this respect inferior to the plumbago and common paper, which, according to the Author, only required a pressure of 10 grammes. The plumbago pencil, however, was much less hardy, and required more frequent renewal than the so-called metallic pencil. The second force was inappreciable in its effect where the vertical pull upon the pencil-carriage was counterbalanced by such a weight as was necessary in most instruments. Where, however, the vertical pull of gravity was insufficient to prevent appreciable deviation from this cause, it was well to allow a portion of the carriage to lie between the two vertical guides with a play of only about $\frac{1}{50}$ inch.

For the comparatively large pressure required to make metallic pencils mark satisfactorily, he believed that this arrangement involved the least possible friction in the case of a vertical drum, or with a drum in any other position, except perhaps that slight inclination from the vertical, by means of which the Author caused gravity to balance the pressure of the paper against the pencil. This was the perfection of simplicity, and was no doubt practicable in tide and river gauges, but not in many other

Deacon. instruments where the moving wire could not conveniently be turned from the vertical line.

As the Author had said, an ink marker had been tried for tide gauges, but had hitherto been found unsuccessful on account of the slowness of motion, and the long time through which the action had to be continued. This, however, was not the case in the fresh water analogue of the tide gauge, viz., the river or reservoir gauge. For some years he had had such gauges constructed with ink markers, and had found them perfectly successful for the slowest motions required in this instrument, and for the quickest motions required in other instruments; while he had not yet discovered the limiting time during which the same pen would continue to mark without attention.

In all respects, therefore, he had found the ink marker greatly superior to any form of pencil, but he had not been able to attain this result with any of the pens ordinarily used for the purpose He had tried a glass pen, and an admirable device, originated by the late Mr. Froude, a metallic pen with an exceedingly fine hole in it, and which at moderately uniform rates made a fine and perfect line. The pen he had used was devised by his assistant Mr. William Davies. The point was a solid cone of brass, fixed in the end of a short tube, conveying the liquid from the under side of the ink reservoir. In the upper side of the cone was a vertica hole $\frac{1}{20}$ inch in diameter, communicating at its lower end with the supply tube, and at its upper end with a little trough passing down the upper side of the cone to its point. The hole was stuffe up with cotton wool, and when the cotton wool was pressed in rightly, the liquid, one-quarter glycerine, and three-quarter aniline dye, passed through it and ran down the little groove t the paper. If the pen moved slowly, and required little ink, th groove conveyed to the hole by capillary action just the necessar quantity; if it went quickly, and required more ink, the groov conveyed a larger quantity. In that respect he had found the pe to answer admirably, and, what was even more satisfactory, th pen never became choked, and so far as he knew its proper actio without attention was only limited by the size of the reservo and by the actual wearing down of the point, which however nee only just touch the paper in order to make a good line.

It was often desirable to place such gauges in places rarel visited by skilled persons, and in such cases it was imperative th they should go for a long period without attention. The pe which he exhibited contained sufficient ink to go for two yea without being touched. Its twin brother had already made

Mr. Deacon

diagram eighteen months long, and he was sure he could trust it for another month. The diagram paper he had been in the habit of using was sufficiently long for three months, but it was generally cut off at one month; the clock also went for three months without being rewound. Instead of ruling the diagrams, he had found that the best way was to allow them to prick their own hours and their own zeros, exactly in the same manner as was done in the Author's tide gauge.

No one could avoid admiring the perfection to which the Author had brought every part of his instruments, but perhaps a little extra motive power would be an advantage. It might not be necessary when there were skilled instrument makers to attend to the instruments, but in isolated places, where men were employed who had not been accustomed to such apparatus, he thought it would be desirable to have the instrument a little stronger, the wires thicker, and the motive power greater. In his own practice he had made the floats from 6 inches to 9 inches in diameter. Possibly that might be excessive, but there was no difficulty about it, and he had found no disadvantage attending it. It occurred to him that there was a possible disadvantage in connection with small floats. In sea water a coating covered the float after a short time, and inasmuch as the motive power was as the square of the diameter, and the effect of the coating would be only directly as the diameter, he thought that a large float would have some advantage in that respect over a small one. He approved of the Author's advocacy of vertical or nearly vertical diagram drums. It was impossible to construct a pen or pencil carriage working in a horizontal line, the power required to drive which would not be a large multiple of the power necessary to move the pen or pencil in any of the arrangements described of vertical or nearly vertical action.

Those who had had occasion to employ recording instruments largely would not fail to appreciate the importance of these details upon which the correctness of their action largely depended.

The Astronomer Ro

Sir G. B. Airy, Astronomer Royal, said, before he entered upon the actual subject under discussion he would advert to a point incidental to it—the formation of fractions whose combination would produce any desired proportion. It occurred on the present occasion in reference to the combination of toothed wheels which would be used to establish the proportion between one argument of an inequality in the tides and another argument. A want of that kind had occurred to him long since, and several years ago he had constructed, with the aid of his excellent assistant, Mr. Ellis, a table

The Astronomer Royal. containing the values of all the vulgar fractions whose numerators did not exceed 100, and whose denominators did not exceed 100, and their logarithms; and those were arranged, not in the order of numerators or in the order of denominators, but in the order of the ultimate value of the fractions; and that gave extraordinary facility for fixing upon any numbers which should represent those values. For instance, if there were any proportion upon which approximate numbers were wanted, taking the logarithm of that proportion and looking over the table, all the fractions whose values approximated to it would be found brought close together. And curious differences would be found amongst them. Two successive fractions seemed to have no relation whatever in the numbers of their numerators and denominators; and the value of the fractions approximated more and more nearly on one side towards that which was sought, and on the other side they receded from it more and more. When the numbers were below 100 (which he should think would always be the case in any practical application), they were taken at sight from the table; when the numbers were greater than 100, and a combination of two sets of toothed wheels was required to establish the desired proportion of results, it would be necessary to go through an operation of addition or subtraction, and the work would be a little longer.[1]

The Paper by Sir William Thomson consisted of three parts. The first was with reference to mechanical improvements in the tide gauge, of which it was sufficient to say that they were made by the Author, who was an excellent mechanic. He was quite sure, from what he had seen, that beautiful instruments would be produced, and that, considering the improvement in general theory in such matters, they would repay the expense incurred. Altogether, he looked upon them as a valuable addition to the mechanics of the science. The third part of the Paper was on the composition of inequalities of various classes for the purposes of prediction, in which it was supposed that each of the various inequalities followed a law like the sines and cosines of angles for different periodic times, and that their coefficients had different values, all of which were to be assigned as the subject of a previous research. There was no doubt that that could be done with the utmost accuracy, and he should think with reasonable safety, although the machine was extremely complex; that was

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[1] The Astronomer Royal has consented to allow the Table of Vulgar Fractions to be printed in the Minutes of Proceedings of the Inst. C. E.—Sec. Inst. C. E.

The Astr
nomer R

in a great measure a matter of mechanical skill. He might say that subjects of that class were not new to him; for when he was giving a series of lectures on the disturbance of the compass in iron ships, first at South Kensington and secondly at the Naval College at Greenwich, he used a model, which still existed at the Royal Naval College, showing by toothed-wheel working, the combination of two inequalities, one depending upon the permanent magnetism of the ship, which had its two terms of sines and cosines, and the other depending upon the induced magnetism of the ship, which also had its two terms of sines and cosines, but repeated twice as often as the others. In fact it was a machine corresponding, *mutatis mutandis*, exactly with that which was used for predicting the diurnal tides. He might also say that he once drafted, but did not complete, a machine for exhibiting the result of the ordinary powers of numbers (decimally expressed) with arbitrary coefficients, and of uniting them so as to form the expression $a + bx + cx^2 +$ &c., exhibiting them in such a way that it would be possible, by sliding a particular part of the machine which received the delineation, to find when the sum vanished, and therefore when the equation $a + bx + cx^2 + \&c. = 0$ was solved.

He had alluded briefly to the first and the third sections of the Paper; he would now speak of the second, which was really the important one, and the one on which he felt great difficulties; namely, the extraction (from a series of delineated tide heights) of the coefficients of inequalities of pre-arranged form. That was a subject which really alarmed one to enter upon, it was so difficult practically and so troublesome. Employing the symbols θ, ϕ, ψ, for different angles, increasing uniformly as multiples of the time, the form assumed for the expression which was to represent the height of the tide was of this kind: $A + B, \sin\theta + C, \cos\theta + D, \sin\phi + E, \cos\phi + \&c.$; and the question was, whether, assuming that form and assuming also the multiples of time which represented successively the angles θ, ϕ, ψ, &c., one could, after that assumption and with the tidal traces before one, extract those multiples A, B, C, D, and so on numerically. That was what occurred in almost everything in connection with physical astronomy and physical research of many kinds, and it was a most appalling process. It was mastered theoretically by a very celebrated theorem, Fourier's theorem, in which the whole series of results taken numerically had to be broken up in parts corresponding to the positive and negative values of every individual of those terms. Sine θ had to be broken up with

Astro- er Royal. reference to the positive and negative values of sine θ; cosine θ had to be broken up with reference to the positive and negative values of cosine θ; in like manner with sine ϕ and cosine ϕ, and in like manner with sine ψ and cosine ψ. There was no other way in which that could be done with accuracy than by so breaking them up, and by adopting successively each one of those functions as the one to whose coefficient importance was wanted especially to be given at the moment, and to multiply separately every term of the equation by the coefficient of that one. For instance he had a long series of terms, including sine θ, cosine θ, sine ϕ cosine ϕ, sine ψ, &c. The first process must be to multiply every line of that equation by sine θ which belonged to it, and to take the sum of those, and then he should get an equation in which the coefficient of sine θ was the conspicuous term So for every one of the others. Conceive what had to be done in such a case! There was a series of records extending over a long time, and it had to be broken up individually for the changes of sign. That had to be done even where they seemed most closely combined. For instance, there were terms well known to the Author of the Paper, of which the period was twenty-four hours, and there were other terms of which the period was nearly twenty-five hours. It might be thought that those two would go together, and on any day they could not be separated; but going twelve days it would be found that one was opposed to the other and there would be a state of things totally different. There wa no way of mastering that except by going through the stric process of separating every one at the proper time; and so for al the other terms of the formula in question. Therefore the whol series must be broken up into a great number of parts, of which i was necessary to have the exact numerical value as deduced from the tidal gauge, or in any other way, and to add those togethe with the different signs plus, minus, according as the sine of th angle was plus or minus; and to do it strictly it would be necessar to multiply every one by a different number, according as th numerical value of the sine or cosine changed. There were som ways in which that immense labour might be alleviated. One wa by assuming that wherever the cosine was plus it might be calle plus unity, and wherever it was minus it might be called minu unity. That amounted to the same thing as saying that whereve the difference of the numbers was to be taken it might be conceived that all that had one tendency had equal values, and a that had the other tendency had equal values, but their differenc must be taken; and that was one alleviation to the great labour

The Astronomer Ro

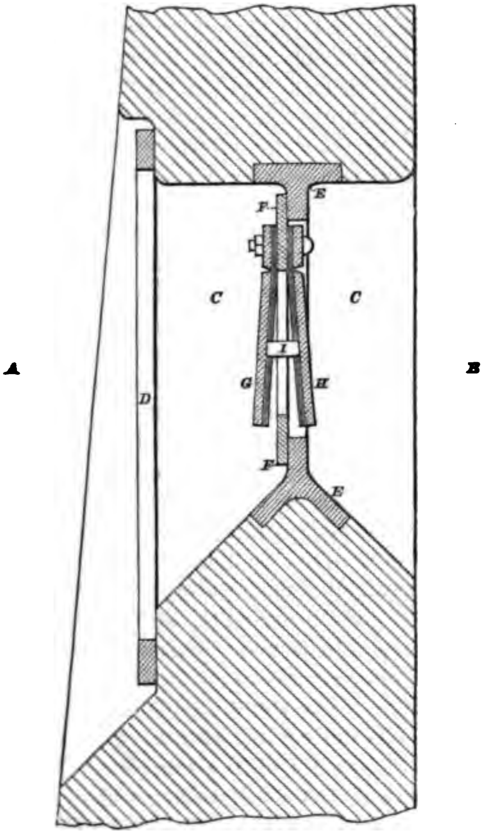
Another alleviation was, that in taking that state of difference all the terms might be abandoned except that which was to be the conspicuous one; and in that case there would be a set of terms for sine θ without the combinations of ϕ's or ψ's; and in like manner another for cosine θ, and in like manner another for sine ϕ, and so on. Still there was this which could not be diminished—that for every one of those terms it was necessary to divide into separate quantities all the records which were to be taken, plus and minus. And all would have their divisions at different times: one would have its division at twenty-four hours, another at twenty-five hours, another at a quarter of a year, and so on; and they could not be combined or separated in any way, but each of them must be actually grouped, and the sums or differences taken in that form. That was the lowest state to which the labour could be reduced. In that lowest state if the machine which was the subject of the communication could make the labour easier it would be a good thing; but he conceived that it was impossible that it could master it. He did not think it possible that it could manage the breakings up to which he had referred; he did not think any mechanism could do it. The mechanism was not sufficiently described in the Paper in order to enable anything specific to be pointed out as to the possibility or impossibility; but speaking in general terms, he did not think that it was possible that mechanism could do it with greater ease than it could be done by the use of figures upon paper. In point of fact, if mechanism were used for the purpose, records must be extracted from it at every one of the breaks of which he had spoken, and transferred to paper for further treatment. He had given his general impressions on the subject. For want of information he could not do it completely; but he had no doubt as to the accuracy of his general conclusion.

Mr. Law.

Mr. Henry Law thought the profession was much indebted to the Author for the perfection to which he had brought these beautiful machines, and for the prominent manner in which he had introduced them to the notice of the members. He hoped that the practical result would be to make the use of automatic tide gauges more general than it had been, because there could be no comparison between the advantages of continuous automatic observations and those which were taken even by the most careful observers. In the case of these latter observations there was not only the liability to error, but, what was much worse, there was the danger that the irregularities to which the tide was particularly subject would be either overlooked

Mr. Law. altogether, because they came between the periods of observation, or, if observed, would be put down as errors. For a long time, indeed until the Rev. Dr. Whewell, Hon. M. Inst. C.E., showed that it was a constant phenomenon, the diurnal variation was regarded in many ports as an error of observation. Again, the automatic gauge gave continuous observations which were of the utmost value, because they showed those peculiar phenomena which occasionally occurred, such as repeated tides, irregularities of tides, and also the special form of curve. Again, they were recorded without labour, and presented the results to the eye in a graphic form, rendering it very easy to draw general conclusions; moreover they were in a form exceedingly convenient for comparison, and for analysis. He therefore thought that such an improvement upon tide gauges, and any such general advertisement (if he might use the word) of tide gauges, as the discussion would lead to, would certainly be a benefit to the profession. On one point his experience agreed with that of Mr. Deacon, namely, that when the tide gauge was applied to the ocean, being subject to considerable oscillation in that case, to use the expression of the Author, a more hardy instrument was desirable, and a larger float He thought there could be no reason for limiting the size of the float. In tropical seas, for instance, where weed and insects grew rapidly, and attached themselves to the float, and would choke and interfere with the appliances which were essential to prevent the oscillations of the water, a less delicate instrument would be desirable. There was a mode which he had used for preventing the oscillations of the sea affecting the records, which had proved perfectly effectual. The Author had stated that at Dover, where, of course, there was considerable motion, a difficulty had been experienced and a suggestion had been made to allow the water to enter the tube through a very small opening; that, however, would soon become choked by seaweed and other obstructions. He had found the method shown in Fig. 13 answer perfectly. Within the line of piles or wall a well should be constructed to contain the float, of considerable diameter, having a channel of communication, the upper side of which should be level; in the centre there should be a diaphragm, and the invert should rapidly slope down in both directions. The diaphragm should have a plate with an opening of 6 inches square, attached to it by two thumb screws, and should have a double valve like Dr. Arnott's ventilating valve, kept at a fixed distance apart. The effect of such an arrangement was that, when a wave rose above its normal height, the tendency of the water to enter immediately closed the valve on that side, and when the wave receded the fall of the water **Mr. Law.** below that in the well, closed the valve on the other side; and consequently there was no disturbance at all in the well. He had found the method effectual, even with waves 5 feet high. Of course seaweed, &c., grew upon the valve, but at low water, by means of the thumb screws, it was easily detached, cleaned and replaced, without interfering with the action of the tide gauge.

Fig. 13.



A. Tidal estuary or river.
B. Well or chamber for float of tide gauge.
C. Channel of communication.
D. Gun-metal grating opening on hinges.
E. Metal frame built into masonry.
F. Movable plate secured in place by two thumbscrews.
G. and H. Hinged valves kept at a constant distance apart by the stud or link *I*.

With reference to the machine for predicting tides, he remarked

Mr. Law. that the circumstances which caused the varying height of the tides might be classified under three heads. First, astronomical, such as the varying declination of the sun and moon, the varying interval between the passage of the moon over the meridian, and that of the sun, and the varying distance of the sun and the moon from the earth. These had a cycle of about nineteen years, and if they were the only circumstances, the tides might be easily predicted. Secondly, the local circumstances, such as difference of latitude, which increased the effect of gravity by diminishing centrifugal force, and increased the attractive force of the particles of water towards the centre of the earth as the latitude increased. Those were constant, and easily calculated. Then there were the influences produced by the peculiar configuration of the bed of the sea, or tidal channels leading to the place of observation. These were not permanent and constant, especially in the case of an estuary or tidal river because, either from slow natural causes or from engineering operations, the circumstances changed, and altered the heights and intervals of the tides. But there was the third class which might be called purely accidental; he referred to the influences produced by meteorological and seismographic causes,—the effects of earthquakes and volcanic influences, which, although rare, sometimes produced great disturbances in the tides. It was evident, he thought, that the most perfect tide predicter would be that which calculated the tide as due to the first two series of causes astronomical and local, eliminating altogether the influences of the weather, which were purely accidental as regarded time, and which were not so inconsiderable as many persons might imagine. The point to which he referred was illustrated by Fig. 14. That was a record of the tides from the 25th of January to the 29th of February, 1836. The dotted line showed the height to which it was predicted, in the tables of the late Sir John Lubbock, that the tide would rise, and the black columns showed the height to which the tide actually did rise at the Shadwell entrance of the London docks. On the 4th of February, for instance, the tide rose above the height predicted, on the next day a little below, on the next, still more below. In one case there was a remarkable tide, 4 feet 4 inches above the predicted height, and on inquiry into the circumstances it appeared that there was on that day a gale blowing from the north-west. The arrows at the bottom of the diagram showed the direction in which the wind blew and the figures denoted the force of the wind according to the Admiralty table. It would be observed that the tides which rose

Mr. Law.

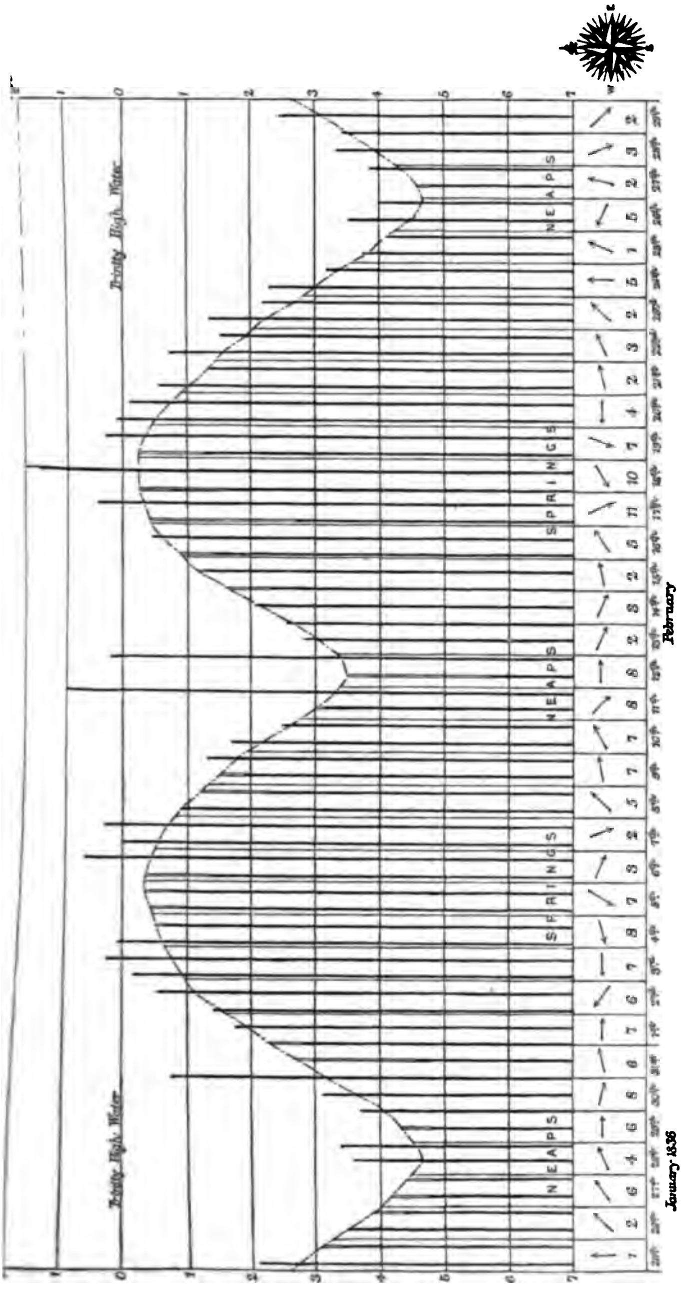


DIAGRAM SHOWING THE INFLUENCE OF THE WIND UPON THE HEIGHT OF THE TIDE AT THE LONDON DOCKS.

Force of the wind.—1. Light airs. 2. Light breeze. 3. Gentle breeze. 4. Moderate breeze. 5. Fresh breeze. 6. Strong breeze. 7. Moderate gale. 8. Fresh gale. 9. Strong gale. 10. Whole gale. 11. Storm.

Mr. Law. above the predicted heights were in every case preceded b
southerly and westerly gales, changing rapidly to northerly an
westerly gales. On the 17th and 18th of February, for instanc
there was the greatest gale that had been known, short of
hurricane. The wind blew with the force of 11, almost northerl
and the tide rose 2 feet 4 inches above Trinity high wate
There was a curious phenomenon which might have been ove
looked (fortunately it was not) by human observation, but whic
would have been recorded with all its incidents by the tid
recording machine. It was a case of a double high water in on
tide, both in the morning and afternoon. The tide rose to
height of 9 inches below Trinity, then fell (he did not kno
how much), and then rose again, and the same thing occurre
at the subsequent tide. This was occasioned by the storm fro
the N.N.W., which by accelerating and increasing the North Se
tidal wave, caused it to arrive so much earlier than the Englis
Channel tidal wave as to produce its own high water, independen
of, and previous to, the second high water, produced when th
English Channel tidal wave (which had been retarded by th
gale) subsequently arrived. It would also be observed that afte
a high tide it frequently occurred that the succeeding hig
water was lower than usual. That was when the disturbance ha
been of such a nature as to affect the general level of the se
when the low water had been raised as well, and therefore t
reaction of the wave carried it down again. The only mode
present of eliminating the effect of these accidental causes was b
discussing an enormous number of observations. Sir John Lubbo
had founded the coefficients of his formulæ upon twenty-fo
thousand observations taken continuously at the London docks-
a series of observations which had been continued to the prese
day. It was by the discussion of these—a work of gigant
labour—that he was enabled to arrive at the means of calc
lating the tides with the great precision with which they we
now predicted. If, therefore, mechanicians could eliminate
mechanical means the accidental effects of the weather, the ha
monic analyser would become of the greatest possible value. I
quite believed that it would be within the range of possibilit
and he had no doubt that Sir William Thomson would see his w
to effecting it. In ports where there had been continuous obse
vations of the wind, the rain, and the barometer, the thr
meteorological phenomena which affected tides to the greate
extent, if the tidal observations were analysed by some modific
tion of the machine, a corrected curve might be obtained, whic

Mr. Law.

being analysed for the tides would afford the elements of the coefficients to enable the tides to be predicted with great certainty. He also thought that the analyser was of peculiar value, because, as had been shown by Prof. James Thomson in his Paper in the Proceedings of the Royal Society, cones might be substituted for disks. He knew that there was a mechanical difficulty in getting the ball to remain at zero with the cones and not to record at that point, but cones might be used instead of toothed wheels for giving motion to the disks, by which means a variation in their angular velocity might be produced. If computers required other functions than those of harmonic analysis, by the introduction of cams of variable form, in such manner that the cone would vary the angular velocity, and the cam would be substituted for the crank, they might be enabled to integrate functions of a much more complicated character, and he had no doubt that the genius of Sir William Thomson would enable him to effect this object.

Mr. Redm

Mr. J. B. Redman said, if any argument were necessary to show the expediency of adopting self-acting tidal gauges at the harbours and great tidal rivers of a maritime country like England, it might be found in the remarkable divergence of opinion expressed after the recurrence of any abnormal high tide in the river Thames. In illustration of that he would shortly describe the conditions of the river on the 18th of January last as compared with the 15th of November, 1875. There were on the Thames four tidal gauges: one at Sheerness, which had been worked for some years, one which had been established a few years at Gravesend, one at Greenwich, and one at the head of the tidal influence at Teddington. There was, he believed, a fifth, the property of the Metropolitan Board of Works, at Crossness. At Sheerness he had frequently, in searching for exceedingly low tides to compare them with the tides in the Port of London, met with a very disappointing and aggravating blank in the record, with a short note stating that the mud had accumulated, and that there was no record of the tide. On the 18th of January last, or a few days afterwards, he was desirous of ascertaining the precise height of the tide at Gravesend, and found from the Conservancy authorities that the tide gauge had been rendered unworkable by the frost; the same thing had occurred at Teddington, and he supposed also at Greenwich. Some remarkable figures had been quoted in reference to the tide of January 18th, and considering the character of the day, the river being covered with floes of ice, and an easterly gale of extraordinary velocity blowing, it was quite intelligible that observations, however carefully made, Mr. Redman. might deviate several inches, as in fact they did. At Sheerness dockyard zero of the gauge was the mean level of the tide. It had been generally assumed as 11 feet 3 inches below the level of Trinity standard in the Thames. That, he believed, was connected by the late Mr. Page; but some years back he had had some correspondence with the authorities at Southampton, and Colonel Bailey took great trouble in looking through the levels, and he found that the observations of the tides at Sheerness, which were contained in the large book of levels of the Ordnance Survey, were made outside the dockyard; and he believed up to the present time had never been connected by direct levelling. Colonel Bailey estimated it at 11 feet 1 inch. On the 18th of January high water at Sheerness was 1 foot 9 inches below Trinity. At Gravesend the tide was 2 feet 9 inches above Trinity, a difference of 54 inches in a length of 21 miles, or 2½ inches per mile. He thought the difference might be explained by the fact that the estuary of the Thames at Sheerness was 5 miles in width; the width of the river at Gravesend was ⅞ mile, and the rapid diminution of the width over the 21 miles of course heaped up the water more rapidly than in the more gradual diminution from Gravesend to Westminster bridge (a length of 29 miles) from ⅞ mile to 800 or 1,000 feet in the Port of London. At Limehouse, the next height to which he could refer with any degree of certainty, at the West India dock entrance, and at the Lower Commercial dock entrance, nearly opposite, the height was 4 feet 5 inches above Trinity, or a rise of 1 inch per mile, 20 inches in some 22 to 23 miles. At the Surrey Commercial dock entrance, and at the London dock entrance opposite, the heights recorded were 4 feet 8 inches above Trinity; the length was 1½ mile, and the rise 3 inches, giving a gradient of about 2 inches per mile. That might be accounted for by the rapid decrease in the width of the river above the Shadwell entrance at Wapping. At London bridge the height recorded was 4 feet 10 inches; 2 miles higher up a difference of 2 inches, or 1 inch per mile. At Westminster bridge the height was 5 feet, a difference of 2 inches in 2 miles, or 1 inch per mile. At Teddington, 17 miles higher up, the height was 5 feet 5 inches. The absolute difference in level of the water surface at Sheerness as compared with Teddington was 7 feet 2 inches. That difference was remarkable, and it would be hardly credited by those who had not looked into the question. The tide of the 15th November, 1875, had this remarkable difference: that it was higher at sea. At Sheerness it was 3 inches below Trinity, and it was correspondingly high at

Mr. Redm

Gravesend, 3 feet 3 inches above Trinity, and yet it was 3 inches lower in the Port of London. This doubtless arose from the great gale of the 18th of January last affecting the water in the narrower metropolitan reaches more than in the estuary and wider lower reaches. Neither of those tides were equinoctial, but ordinary springs. That of 1875 after a great west gale, changing to north, was 3 feet 3 inches above the forecast, but that of the 18th of January was absolutely 5 feet above the estimated height, due to the great east gale, and in all probability the greatest excess on record. The phenomena at low water showed also the necessity of automatic gauges on the river. The tide in the Port of London ebbed considerably below that of Sheerness. He knew that it was discredited by many, but it was an absolute fact: those who disputed it forgot that in addition to the difference in level of the respective low waters that at the moment of low water in the Port of London the tide had risen 2½ hours at Sheerness—⅓ of the tidal flow, and that at the same instant the level of the water at Sheerness was 6 feet higher than it was in the Port of London. In fact the momentum of the ebbing water continued until it was overcome by the head of water from the sea. There was one point to which he desired to refer in reference to the fixing of the gauges—the great importance of having shafts removed away from the tide margin, which would allow the float to oscillate vertically through the entire passage of the tide. There was now an ebb of more than 23 feet below Trinity in the Port of London, and a maximum flow of 5 feet above Trinity. Shafts were wanted at least 30 feet in vertical height. Then the connection between the shaft and the river was of great importance. Sir William Thomson had referred to that fact in reference to Dover. The only practical difficulty was the checking of the undulatory motion, caused by passing steamers, and the question of frosting up the float. An arrangement of diaphragms in the connecting tunnel or culverts with the vertical shafts, or perforated diaphragms, was necessary. He thought that the connecting culverts in the Thames at least should be in duplicate, so that they might be pumped out and cleansed ultimately without interfering with the work of the gauge. Last and not least in importance, was the question of zero of indices sufficiently low to avoid minus readings? At present there were no less than four data in the Port of London, viz., Trinity standard, Ordnance datum, and two Admiralty low-water levels.

Mr. Cush

Mr. T. Cushing remarked that the Astronomer Royal had observed that to the ingenuity of the Author was due the improved

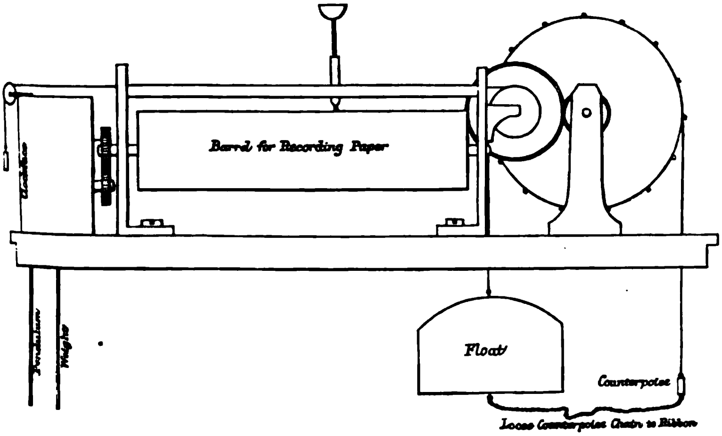
Cushing. mechanical appliances now used in connection with tide gauges, and in this remark he to a considerable extent agreed; but the fact must not be overlooked that much credit was also due to others who had laboured in the same field. The Author, in describing his tide gauge, remarked that "for the present at all events, a pencil is by general consent the marker of an automatic tide gauge." Now, in the Loan Collection of Scientific Apparatus at South Kensington, in 1876, there was exhibited, by the Royal Prussian Geodetic Institute of Berlin, a tide gauge in which the marking point was a diamond. In that case the recording cylinder was covered with blackened chalk paper, and the diamond point, in obedience to the motions of the float, cut away the black surface, leaving a beautifully fine white line on a black ground. Again, in the year 1873, Professor van Rysselberghe, now of the Royal Observatory, Brussels, designed an automatic tide gauge for the Port of Ostend, in which the marker was a diamond point; but in this case the record was not made on paper, but on a sheet of ordinary zinc. The zinc was by a very neat arrangement fixed round the recording cylinder after having been coated on one side with etching varnish, and on this side the diamond point drew the tidal curves for seven days; the plate was then removed and dipped in etching fluid, and after that any number of prints could be taken from it. He possessed prints for the whole of the year 1878, taken from the plates automatically engraved by the Ostend instrument, an inspection of which would show that not only could the state of the tide be accurately determined at any given time, but that the time and the height of each individual wave was recorded, and he ventured to think that no less refined marking point would give such a result. In the next place the Author said that in his present tide gauges "the motion of the marker is vertical, the axis of the paper cylinder being vertical, instead of both being horizontal, as had been the case in nearly all previous tide gauges." This statement hardly agreed with the present state of knowledge on the subject, for many previous tidal machines had their recording cylinders placed in a vertical position. In Bunt's tide gauge, at Bristol, one of the first ever constructed on the automatic principle, and described, with illustrations, in the Philosophical Transactions in the year 1838, the recording cylinder was vertical. The instrument of Professor van Rysselberghe, just referred to, and erected on the eastern pier at the entrance to the Port of Ostend, and which engraved the plates from which the beautiful curves he exhibited were printed, had its cylinder vertical. Professor van Rysselberghe had also designed similar tide gauges, which were erected at Antwerp, Dendermonde, Tamise, and other places in Belgium, all of which had their cylinders placed in the same position. Then there were several tidal machines at present in this country recording the tides on vertical cylinders. He might also mention that Colonel Sankey, R.E., designed in 1870 what he then called a flood gauge, intended for automatic registration in Indian rivers and tideways, with a vertical registering barrel. One other point might be mentioned with reference to tide gauges, and that was with regard to the scale of the instrument. It was a common thing, as the Author said, to make the motion of the pencil from one-tenth to one-hundredth of the motion of the floater; but in the twelve large tide gauges constructed by Mr. Adie for the Government of India in 1878-79, and now employed on the tidal operations of the Great Trigonometrical Survey in that country, the scale of each instrument could be adjusted at pleasure, so that the motion of the pencil was either equal to the rise and fall of the float itself, or was equal to a scale of $\frac{1}{2}$, $\frac{1}{3}$, $\frac{1}{4}$, $\frac{1}{6}$, or $\frac{1}{8}$; in the latter case the instrument was capable of registering a tide of 40 feet, the counterpoising of the pencil carriage, so as to keep the friction as nearly as possible constant under all circumstances, being most effective, and he had reason to believe that the instruments had given great satisfaction to the officers of the department in which they were employed. Mr. Cushi

With regard to the Tide Predicter constructed for the India Office by Messrs. Légé and Co. he had had many opportunities of seeing it both in and out of action, and, whatever theoretical opinions might be held regarding it, he was sure there could not be two opinions as to the way in which it performed its work. It was a masterpiece of mechanism, reflecting the highest credit both on the designer and the constructor. The instrument took nearly five hours to work off the tidal curves of a given port for one year, including winding up the driving weight, &c. The Author considered this too slow a rate of working, but even with this speed the whole of a year's tides for five hundred different ports could be predicted in less than a year. It was true that some loss of time occurred in winding up the driving weight of this machine, which was at present 560 lbs; but this weight was distributed over a quadruple line to suit the exigencies of the building in which it was placed, which also necessitated a number of pulleys to lead off the weight to a convenient place, each of which meant more friction and additional weight to overcome it. He had no doubt that the machine could be driven at full speed

Mr. Cushing. with less than 100 lbs. weight on a single line if there was sufficient fall provided for it, and he thought this did not indicate much friction in a complex machine having something like two hundred and fifty moving parts, some moving with high velocities. It ought perhaps to be mentioned that it was originally intended to send this predicter to India, hence the necessity for providing a driving clock of some sort. But there were two ways of getting rid of the loss of time occasioned by winding up; first, by adopting Mr. Légé's idea of driving it by a small turbine, which was quite practicable where the machine was now placed, as there was a fall of water in the building of something like 80 feet. The second plan was to adopt Mr. Cooke's method of maintaining power, which had this advantage over all other maintaining powers with which he was acquainted, that the driving power of the machine was continued, however long the winding up might take. Either of these methods could now be adapted to this machine at a small cost, and would dispose of what he believed to be the only ground of objection which could be raised against it. A few specimen curves were drawn with this machine in the room in which the time scale was printed across the paper; this was done at the same time that the curves were drawn, and greatly facilitated the reading off. The arrangement for doing this was not included in the original design, but was added before the completion of the machine, and he had found it work well, as the specimens which he had produced clearly showed. The curves were drawn on a continuous band of paper to a particular scale; that scale was fixed by the present tide gauges in use in India, so that the paper on which the predicted curves were drawn might be sent out and compared with the curves drawn by the actual tides. His own opinion was that in future some arrangement, similar to that of Professor van Rysselberghe, would be adopted for recording the predicted curves by means of a diamond point upon copper or zinc plates, which would allow a fortnight's or a month's curves to be drawn on a single plate. The lines being very fine, and at the same time well defined, would enable a smaller scale, if necessary, to be adopted.

Mr. Adie. Mr. P. Adie desired to say a few words on the subject, because he felt that he was, to some extent, practically involved in the matter. Ten or twelve years ago, Colonel (now General) Walker applied to him to recommend the best form of gauge for the observations which he was desirous of taking in India in connection with supposed changes in the relative heights of sea and land in different parts of the Peninsula, and for which purpose he had now altogether made about twenty gauges (Fig. 15). He explained to him that the observations were to extend over a period of from ten to twenty, fifty, or, it might be, one hundred years. Of course, to meet such a case, it was his business to find out the most durable instrument that could be suggested, and, with that view, he adhered very much to the old style. He did not know who was the inventor, but the first maker of the pattern that he was aware of was the late Mr. Newman of Regent Street. As to the question of vertical and horizontal cylinders, he had tried it experimentally. Twenty-five years ago he had put up a vertical one for the Metropolitan Board of Works. It was rather too large in diameter and for comfortable manipulation, and he never liked it, especially as it did not answer for large heavy cylinders. As to the question in itself, he really thought that there was nothing in it. He looked upon a horizontal cylinder as being preferable, simply because it was more easily driven by the clock, and because the friction was more easily reduced. As to the question of friction, in the matter of registering with accuracy, he did not think there was much in it because the ocean afforded unlimited power, and therefore the float might be of any size. He saw no reason for circumscribing the power of the machine or diminishing the float. As he would give preference to a machine over a model, so he would make a tide gauge practically more of a machine than a model. He was guided by those principles in recommending the old form. He had brought a portion of a small **Mr. Adie.**

FIG. 15.


Barrel for Recording Paper
Pendulum
Weight
Float
Counterpoise
Loose Counterpoise Chain to Ribbon

Tide gauge $\frac{1}{10}$ real size.

Mr. Adie. tide gauge to illustrate what he meant with regard to friction. If the float were pressed gently into the water and allowed to return of its own accord, and then by reverse process pulled gently out, and the difference observed on the full scale, as shown by the index against the wheel carrying the float, the greatest magnified error possible would be under $\frac{1}{10}$ inch, while the motion of the water corrected for this, and that on the diminished scale, was quite inappreciable. Another point might be added, that this pattern of gauge, while it was strong and durable, was much less costly than the other specimens shown. He did not like the results of diamond marking when he saw them.

. Symons. Mr. G. J. Symons did not propose to allude to the purely tidal question, his acquaintance with tides being very slight, but he had had a little to do with self-recording machinery, and, with profound respect for the Author, he thought he had gone in the wrong direction in throwing away the motive power of the ocean. He could not help thinking that it was a mistake to try and work with so small a float. He had had considerable experience in trying to get a record of the measurement of evaporation. He wanted a record of the changes of water level to the hundredth of an inch, which of course was not a very easy thing to accomplish. The only mode was to use the largest float that could be got. The smaller the float obviously the less the motive power, and the less the motive power the more the element of friction came to counterbalance it. It was not as if one could always have the apparatus in one's laboratory. The Author had spoken of locking it up for twelve months. In most places, however, spiders' webs and such things would probably come in the way and form a disturbing element. A proof of that might be found in the statement of Mr. Redman as to what had happened with respect to the tides in January; for out of four or five gauges three had broken down. With regard to pencils, they were no doubt a source of great trouble. If they broke just when the machine was going to be wound up it would not matter, but they were sure to break at some other time. A great deal had to be learned from our continental friends. The method of engraving on plates or marking on blackened paper cylinders, as explained by Mr. Cushing, gave a very delicate line, which could be read with ease to the $\frac{3}{1000}$ or $\frac{4}{1000}$ of an inch. It might be thought that such cylinders were awkward to manage, but they were not so, and the result was superior to anything that could be obtained from photography or by pencils. One point with regard to tides had not been mentioned. Hitherto the suggestion had been that

Mr. Symo

the main disturbing element in tides produced by meteorological causes was due to the wind. As a rule that was no doubt the case, and almost always in regard to rivers, except that some confusion arose from the coming down of the land-water. There had, however, been some most remarkable tidal disturbances in connection with thunderstorms. In the case of certain thunderstorms, there had been obtained most peculiar curves from self-recording barographs, showing a most marked variation in atmospheric pressure; and the same thing occasionally occurred in regard to tides. Mr. Cushing had just handed him an illustration of that in the Ostend records for 1878, but it was nothing like the extent of the variations to which he had alluded. In Pegwell Bay in 1858, during a sharp thunderstorm at nine o'clock in the morning, the water went out about 200 yards with a sudden rush, and in a short time came back again.[1] The same thing had been observed at Penzance, and had been the subject of Papers written by a gentleman residing in that locality.[2] There were also earthquake-waves, which afforded a strong argument for the erection of self-recording tidal gauges to trace their progress. It might be remembered that on the occasion of one of the violent earthquakes in South America not long ago the shock produced such a disturbance of the ocean that it travelled across to Australia, and was recorded on the tide gauge in Sydney harbour. He was afraid that the element of cost had not been sufficiently taken into consideration in regard to self-recording instruments. Many cases had occurred in his experience in which an automatic record of what had happened, as to the flow through sewers, or the amount of rainfall, or the changes in river levels, would have prevented expensive law suits; and if such records could be made simply and cheaply, a great advantage would be obtained. He could see no necessity for the great expense hitherto attaching to such apparatus. There was a simple apparatus used in many parts of London for measuring the pressure of gas in the mains, and he should imagine that an instrument of that kind could be turned out for a fourth or a fifth of what was paid for tide gauges. With regard to the communication between the shaft in which the floats were to work and the open sea, he was afraid that barnacles would get in the way of the flap-valve suggested by Mr. Law. If there

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[1] *Vide* "Symons's Monthly Meteorological Magazine," vol. iii. (1868), p. 81.

[2] *Vide* "On the two great Thunderstorms, with extraordinary Agitations of the Sea, in 1846," by R. Edmonds; and "On Earthquakes and extraordinary Agitations of the Sea."—"Phil. Mag." Jan. 1866, p. 45.

Mr. Symons. were a considerable number of them they might trust to the majority of them working all right, but he could not help thinking that the arrangement was a risky one, and he should prefer trusting to a multiplicity of small straight tubes.

Mr. Cowper. Mr. E. A. COWPER said it should be borne in mind with respect to the question of friction in the case of floats, that there was a constant slight motion produced by the waves, both above and below the average line, he therefore could not conceive of there being any error due to friction. It was just like tapping the barometer, which practically did away with friction.

Sir William Thomson. Sir WILLIAM THOMSON, observed, in reply, that Mr. Roberts had criticised the platinum wire used in tide gauges put up by himself, or under his advice. He had chosen platinum wire because it appeared to him to be more durable, and less likely to be disturbed by the moisture and the action of sea-water, and of sulphurous emanations in the case of tide gauges for harbours or rivers, than any other available substance; and he saw no reason to recede from the opinion which had primarily led him to its adoption. The only other substance comparable with platinum wire, in regard to those qualities, was gold. Platinum, however, was much stronger than gold, and he had no hesitation in giving it preference. Mr. Roberts, in speaking of the harmonic analyser, had referred to the total omission of all long-period tides both in the completed machine (of which the drawing was exhibited) and of a suggested second machine which he had sketched. Means for evaluating the long-period tides had not been omitted. The disk, which revolved uniformly, gave the true average of the height, and by reading it off once every month twelve data were obtained, from which it was perfectly easy to work out, in a few minutes, the annual and semi-annual tides. In the work done by him from year to year for the Tidal Committee of the British Association, they were found to be of great importance, and, as Mr. Roberts had said, it was necessary to take them into account in tidal predictions. He was glad to listen to all remarks on the scientific questions that had been brought before the Institution, but he did not think that anyone could be pleased to have such subjects brought forward as Mr. Roberts had introduced in the latter part of the statement which he had made. Mr. Roberts had stated that he was present on board the Author's yacht in August 1872, when Mr. Tower suggested, among other possible methods of combination, that of the chain and pulleys. It was not until after Mr. Roberts had left the yacht, and Mr. Tower and himself were making a journey in a railway carriage

Sir Williai Thomson.

from Portsmouth to Brighton, that Mr. Tower suggested that method of combination. With regard to that exceedingly good suggestion, it had been pointed out to him within the last few days that it had been realised long before by Mr. Bashforth, in a machine which he described to the British Association at Cambridge in 1845. An account of a machine involving the same plan for the construction of simple harmonic motions had been communicated to the Royal Society on the 17th June, 1869, by Mr. W. H. L. Russell, in a Paper "On the Mechanical Description of Curves." The "Philosophical Magazine" for 1870 (vol. xxxix., p. 304) contained an abstract of that Paper, with a drawing of the very instrument, of the existence of which Mr. Tower and himself were ignorant. Mr. Russell went back to Mr. Bashforth as having described the machine in 1845, and referred to him as the originator of it. Only a short abstract of the description was published in the volume of the British Association for the Cambridge (1845) meeting (Trans. of Sections, p. 3). They had Mr. Russell's authority for the statement that the machine was the same as that which he (Mr. Russell) described, and of which he gave a diagram. Mr. Roberts had quoted from the *Athenæum* report of the Brighton meeting of the British Association in 1872, a statement obviously fragmentary. "Each elementary tide gives a height of water proportional to the height of the end of a clock hand, which makes one revolution with uniform speed during the period of the elementary tide." That was, in fact, a description of the first essential structure or foundation of the tide-predicting machine. What was wanted to complete it was something to combine the motions of bodies, each moving, so as to be on a level with the end of a clock-hand moving in the manner described. Mr. Roberts stated that he (Sir W. Thomson) did not describe to the British Association at Brighton Mr. Tower's method of combination of pulleys and chain. What, however, was more to the purpose, in respect to Mr. Roberts' allegations, he wrote to Mr. White, before the end of the meeting, ordering a model to show the combination by hair-spring and pulleys; and he informed Mr. Roberts before the end of August 1872 that he had done so. Sir W. Thomson described to the British Association the multiple revolving clock-hands, each separately showing one tide, with a crosshead to give the simple harmonic motion, and he described to Mr. Roberts the method of combining by chain or hair-spring and pulleys. Mr. Roberts, believing Sir W. Thomson had abandoned the sliding crosshead, and believing that he had abandoned the hair-spring and pulleys, unknown to the Author, gave Mr. Légé, in February 1873, Sir William Thomson. directions to construct the two-component model with crossheads and chain and pulleys. Mr. Roberts was in the employment of the British Association Tidal Committee, being paid to make calculations for that committee. He was working under Sir W. Thomson's direction as chairman of the committee. Taking two methods which he believed Sir W. Thomson had discarded, one of which was all the world's, and the other was Mr. Tower's, Mr. Russell's, and Mr. Bashforth's, he stole a march upon him, as he supposed, in constructing the machine. He omitted to say that it was constructed at Sir W. Thomson's expense. The Author had in his hand Messrs. Légé's account for the completed instrument, headed, "Makers of Sir William Thomson's Tide Calculating Machine," and certified by Mr. Roberts, which was presented to him by Mr. Roberts for payment. Mr. Roberts had explained that a false label, by mistake, had been attached at Bradford to the machine in 1873, and he had apologised to the Author for the mistake; but now, in 1881, he adopted the effect of the false label in the description "Mr. Roberts' machine." Mr. Roberts had referred to his communication to the Royal Society of the 19th June, 1879. It was necessary to explain that, wishing to do every possible justice to Mr. Roberts, to give him an opportunity of coming before the Royal Society as having had the superintendence of the construction of the tide-predicting machine for the India Office, he had asked him to write an account of it, and said that he would himself communicate it. He had gone so far as to read the Paper to the Royal Society. After doing so he pointed out that a change of title was absolutely necessary to give a true account of the origin of the instrument, and that he thought the title which appeared was an inadvertence. He was exceedingly surprised to find that Mr. Roberts adhered to his title, which seemed to imply that the instrument was a new one, invented by himself. He then withdrew from being the communicator of the Paper, and he arranged, in consultation with Professor Stokes that he, as Secretary, should communicate it. Sir W. Thomson had not taken any notice of the matter for two years, and one result was that, in the *Engineer*, the machine was described as Mr. Roberts' Tide Predicting Machine. In fact, no detail of the India Office Tide Predicter, any more than of the two-component model and the South Kensington Tide Predicter, was due to Mr. Roberts, except the arithmetical design of the wheel gearing. Mr. Roberts said that "he was exceedingly pleased that in the Author's projected predicter, he had again reverted to Mr. Roberts' original plan of

Sir William Thomson.

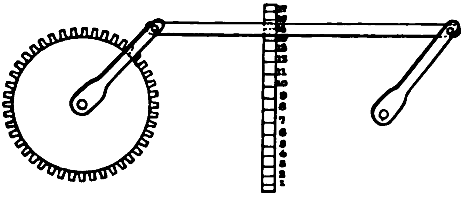
slides." Mr. Roberts' idea in 1872 of a parallel slide, or of the best mechanism to serve for one, was illustrated by the following extract from a letter to Sir William Thomson:—

"MR. EDWARD ROBERTS TO SIR WILLIAM THOMSON.

"85, HIGH STREET, HASTINGS.
"*Aug.* 26, 1872.

"I have been thinking of the Calculating Machine, and I think that the chief (and apparently the only) difficulty, will be in the combination; and I think that the simplest mechanism will be the best—a movement similar to the connecting-rod of the driving wheels of a locomotive, giving the range of each tide component.

FIG. 16.



This movement will give great power, and will not readily get out of order."

The India Office Tide Predicter, notwithstanding the serious faults referred to in the Paper, was a beautiful and grand piece of mechanism, and its construction did the greatest credit to its maker, Mr. Légé. Its usefulness was such that the Indian Government might be congratulated on the results of the expenditure, though heavy, which it had involved. The great fault of the mechanism,—the endless screws and the high speeds of their shafts,—was objectionable, not only because of the limitation of the speed of working to the four hours for running off a year's curves, but also because it necessitated an amount of driving power which was excessive, considering the work done. Attempting to make the fault seem of no importance, Mr. Roberts said, "The Author's objection to the limit of speed of working of the India Office predicter was not a valid one; the machine, being automatic, could be set over night, the traced curves being ready for manipulation the next morning." He had omitted to say that it had to be wound up (a process taking twenty minutes) three times in the course of the work for one year, stopping the work each time during ir William 'homson. the twenty minutes' winding. Thus, if it was to do a year's curves in the course of a night, the person in charge would have to get up twice in the night to wind it, and spend twenty minutes each time to do so. It was worked by a weight of 5 cwt., descending 26 feet for four months' work. That weight had to be wound up three times to a height of 26 feet to get through a year's work, and the whole time of winding-up was an hour for a year's work of tracing the tidal curve. Mr. Roberts was unwilling to admit that a machine which completed a year's work in twenty-four minutes was an improvement; but he (Sir Wm. Thomson) thought that to do the same work with less heavy and less costly and simpler mechanism, and tenfold greater speed, would generally be considered a great improvement. Mr. Roberts objected to No. 3 tide predicter in respect to accuracy of the speeds. He could scarcely have examined into the figures, or with his known skill in arithmetic, he would have made no such remark. The Table of speeds in Part III. of the Paper showed as the greatest amount of error 1°·95 in half a year; and this on the (MS.); a tidal constituent, which was of small amount, depending on shallow water, under the combined influence of the sun and moon. When it was remembered that the instrument was essentially re-set in respect to epochs for each year's work, it would be seen that the error arising from want of accuracy in the speeds was absolutely nil—that, in fact, it was impossible practically to perceive any effect of the difference between perfect accuracy and the degree of accuracy given by the numbers in the Table, in the results of the work of the machine.

As to Mr. Roberts' objection to the 802 teeth in one of the wheels of the No. 3 tide predicter, the Author had found the primary and secondary N wheels with their 802 and 423 teeth to work perfectly well. He had no difficulty in keeping them geared together. The diameter of the wheel of 802 teeth was not 15 inches, as supposed by Mr. Roberts to be the smallest practicable: it was 6 inches, as shown in the full-size drawing before the meeting.

Referring to the Astronomer Royal's remarks on the problem to be solved by the Harmonic Analyser, let

$$y = A_0 + A \cos nt + B \sin nt + A' \cos n't + B' \sin n't \\ + A'' \cos n''t + B'' \sin n''t,$$

be the theoretical equation of the curve given by the self-registering instrument, whatever it be (tide-gauge in the special case before the meeting), or given by plotting properly the observations

Sir Willi
Thomson

(as in astronomical applications, pointed to by Sir George Airy). The nt, $n't$, $n''t$ corresponded to the θ, ϕ, ψ of Sir George Airy's verbal statement. The several counters of the machine, after it had been worked through a space corresponding to a whole time, T, gave the values of the integrals $\int_o y\,dt$, $\int_o^T \cos nt\, y\, d\,t$, $\int_o^T \sin nt\, y\, d\,t$, &c. Thus if C_o, C, D, C′, D′, C″, D″ denoted the readings of the several counters, there would be the following seven equations to determine the seven unknown quantities A_o, A, B, A′, B′, A″, B″:—

$$T\,A_o + \frac{1}{n}\sin n\,T . A + \frac{1}{n}(1 - \cos n\,T)\,B + \&c. = C_o,$$

$$\frac{1}{n}\sin n\,T . A_o + \frac{1}{2}\left(T + \frac{1}{2n}\sin 2\,n\,T\right)A + \frac{1}{2n}(1 - \cos 2\,n\,T)\,B + \frac{1}{2}\left.\frac{\sin(n-n')\,T}{n-n'} + \frac{\sin(n+n')\,T}{n+n'}\right\}A' + \&c. = C, \&c.$$

Here, provided T was large enough, the coefficient of A_o was relatively very large, and all the others small, in the first equation; that of A was relatively large, and all the others small, in the second equation, and so on. Hence approximately (more and more approximately the larger was T),

$$A_o = \frac{C_o}{T},\ A = \frac{2\,C}{T + \frac{1}{2n}\sin 2\,n\,T}, \&c.$$

If T was not large enough to make these approximations sufficiently close, the first approximate values of A, B, A′, B′, A″, B″, were to be used in the equation for C_o above, and a second approximate value for A_o was then instantly calculated by it. Similarly the first approximate values of A_o, B, A_1, &c., were to be used in the equation for C, and a second approximate value for A calculated from it, and so on for B, A′, B′, A″, B″. These second approximate values were in most practical cases as accurate, practically speaking, as the available observations could give. Thus the Harmonic Analyser really did the work which seemed to the Astronomer Royal so complicated and difficult that no machine "could master it."

An interesting point had been brought forward by Mr. Cushing in connection with engraving curves, and he had shown a beau-

Sir William Thomson. tiful specimen of the Ostend tide curves. He did not quite agree with him in his objection to the pencil. He had not the slightest difficulty in getting a sufficiently fine line with a pencil, and he therefore objected to introducing anything less simple. The diamond was valuable when they wished to engrave the result; but when that was not required it was an unnecessary expense. He knew of no case in which the pencil had been broken. With regard to the floater, he did not neglect the great power of the ocean, but he would not use a windmill 30 feet in diameter when a windmill 30 inches would suffice to do the work; and on that principle he preferred the smaller floater and a finer line connecting the floater with the wheel to the enormous floater shown by Mr. Adie, involving large expenditure to provide a large enough tube under water to guard it. Another reason for not making the floater too heavy was that in case of accident it should not be able to break the wire. He liked to have the wire strong enough to bear the floater. It would not do to have it too strong, or it would not be flexible enough to go round the pulley; and the strain must not be too great or the ink-marker would have to be too heavily weighted. He desired to call attention to a model made since the last meeting, and placed before the present meeting, showing the epicyclic method of combination, which he had explained at the commencement of the discussion on the present Paper, and which he had first described more than nine years ago to the British Association at Brighton. It was the very simplest of all ways of combining two constituents. It was essentially limited to two, and for some time he contemplated introducing it for combining the two chief tidal constituents, the lunar semi-diurnal, and the solar semi-diurnal in the predicting machine. He had given Mr. Légé instructions for making the model only last Tuesday, and it was now exhibited to the members; having been made according to the drawing (Fig. 12), which they had seen at the last meeting. This plan had an interesting feature—it showed to the eye the priming and the lagging of the tides. Thus it showed that the times of tides were unaffected by the disturbing influence of the sun at spring and at neap tides, but that the amplitudes were affected. It showed exactly how at the quarters intermediate between neap and spring tides there was a lagging or a priming.

Correspondence.

Prof. Eve

Professor J. D. EVERETT pointed out a modification of the harmonic analyser which would adapt it to the search for one or more cyclic periods in a continuous record of any variable quantity. The adaptation consisted in having only one pair of cranks at right angles, with their Disk-Globe-and-Cylinder Integrators, instead of several pairs, and in having changeable toothed wheels to give the speed. A speed approximately corresponding to a cyclic period would give as the result of the mechanical integration an amplitude of sensible amount; and the amount would increase as the approximation was made closer by a slight change of speed.

This modification would greatly reduce the size and cost of the machine; but in applying it to the calculation of tidal constituents, the tracer would have to be carried over the curve once for each constituent; and in passing from each constituent to the next, the speed wheel would have to be changed.

Mr. Parl

Mr. WILLIAM PARKES could testify that there was a wide field for the action of the Author's three very beautiful machines. In India the first was already at work with valuable results, under the direction of Captain Baird, R.E., in obtaining records of the tidal movements at various points of the coast. These records were being analysed, though not as yet, he believed, by machine, and from the results obtained the curves of future tides for eight Indian ports were now drawn out by the predicting machine under Mr. Roberts' directions, reduced to figures, and published under authority of Government as Tide Tables.

Mr. Parkes had been a labourer in this field for some time before the Author brought his great abilities to bear upon the subject; and he ventured to think a short statement of the results obtained might be interesting, although, since the matter had been taken up by the Author, he had left the pursuit of it to him and those who were working on the principles laid down by him.

Twenty years ago very little was known of the tides of the Indian seas. Their range was known to be small, and there were departures from the regular semi-diurnal movements, which were described on charts and in sailing directions as "irregular" or "anomalous," and generally attributed by the "alongshore" authorities to the ever-ready "southerly breeze somewhere out at sea."

A few short series of consecutive observations had found their

. Parkes. way into the hands of scientific men, and had been analysed as far as possible. There were Papers in the "Philosophical Transactions" by the late Rev. Dr. W. Whewell, Hon. M. Inst. C.E., on the tides of Singapore, Petropauloski, and one or two other places, but the information was too meagre for any practical result. The theory was exhaustively treated by the Astronomer Royal in his elaborate treatise on Waves and Tides, in the "Encyclopædia Metropolitana;" but there were few observations to compare with the results of his investigations.

In 1857–58, Mr. Parkes was engaged for about five months in an engineering survey of the harbour of Kurrachee, and during the greater part of this time he had a continuous record kept of the height of the tide at every five minutes night and day. These records were plotted as continuous curves, and the heights and times of high and low water were also plotted in diagram form. The diagrams showed clearly that the general idea, based on the observation of European tides, that high and low waters were phenomena of nearly uniform semi-diurnal occurrence, was a most inadequate one as applied to Indian tides. The departures from the uniform recurrence of semi-diurnal tides were evidently not irregular nor anomalous, but followed laws as regular and definite as those which governed the semi-diurnal tides themselves. The feature of "diurnal inequality" was known to exist in European tides, but was so small compared with the semi-diurnal range that it was not considered of practical importance, and no general law for its prediction from astronomical data had been determined. But in the Kurrachee tides alternate high waters would at certain periods differ 2 feet in height, and three to four hours in time, and low waters 6 feet in height and an hour in time. Thus a rise of 6 feet in four hours might be followed by a fall of 6 inches in seven hours, that again by a rise of 3 feet in eight hours, and that by a fall of 8 feet in five hours. The regular recurrence o these alternations at intervals of about a fortnight showed tha they were due to the influence of the moon. This short series o observations then showed that there was a new field for tida investigation which had been hitherto comparatively untouched It was the nucleus of a collection of observations on which h founded a course of investigations extending over several years which produced results of considerable practical value, and whicl he relinquished only when it became evident that the Author's proceedings were likely to attain the same end, and by means in some respects superior.

In the earlier part of his investigations Mr. Parkes received valuable suggestions from the Astronomer Royal, and that gentleman kindly communicated to the Royal Society a Paper by him descriptive of his processes and results, which was published in the "Philosophical Transactions" for 1868.[1] Mr. Park

In 1846 a self-registering tide-gauge had been established at Bombay, and the first three years' records of this were lent to Mr. Parkes by the Admiralty. The machine, however, had not been properly attended to, and it was found that only the first year's records were in any degree reliable, and those were imperfect. The machine was kept at work up to 1864, when he inspected it, but its adjustments had been neglected, and the later records offered no encouragement for investigation.

The records, however, so far as they were reliable, showed that the features were very similar to those exhibited in the four months' records at Kurrachee. A portion of them had been subjected to an elaborate process of investigation, the results of which had been published in the "Bombay Magnetical and Meteorological Observations for 1862;" but it was remarkable that the investigator appeared to have entirely failed to observe the particular feature which distinguished these tides from those of the North Atlantic.

In 1864 Mr. Parkes again visited Kurrachee, where harbour improvement works were then in progress, and at his suggestion a self-acting tide-gauge register was taken for the six months from March to August 1865. This was the basis of his further investigations; but the register was continued for several subsequent years, and was made the basis of some of the earlier harmonic analyses by Mr. Roberts. Mr. Parkes used the later records principally to compare with the predictions which he had made by formulæ based on the investigations of the previous records, and to correct the processes where necessary.

The method of investigation adopted was a graphic one, similar to that which had been used to a limited extent by the Rev. Dr. Whewell in some of his tidal investigations. A great advantage of this method was that the changing values of recurring phenomena were exhibited to the eye, and the critical epochs were at once made evident. The progress of time was represented by the abscissæ, while by the ordinates was represented the successive facts requiring investigation. On the first set of diagrams were represented the height of the water at small equal intervals of time; on the second the successive maxima and minima, or high waters

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[1] *Vide* vol. clviii., p. 685.

. Parkes. and low waters; on the third the intervals of the times of hig
and low water after the moon's transit. These diagrams agai
suggested others, and the result was that almost every measurabl
value connected with the rise and fall was drawn to scale.

Then as all these values consisted of several components, some
known, others of unknown value, the former could be separate
from the latter for separate treatment. Thus, any one given fa
could be cleared of a number of disturbing elements before bein
admitted into a group for averaging, and its value as a fact thereb
enhanced. In this way the records were dissected and analyse
without reference to theory of any kind, and the result was th
periods and epochs of the tidal changes were identified wi
periods and epochs of the movements of the sun and moon, wi
which at first they appeared to have no connection. One of t
most important results of the graphic system of analysis was t
separation of non-tidal variations of level. The several high a
low waters being plotted from a fixed datum, lines were draw
through them, and then an intermediate line drawn eq
distant from them. This line showed the changes resulti
from long period tides and non-tidal causes. By eliminating t
difference between this line at any given point and its mo
distance from the assumed datum, an important disturbing eleme
in the diurnal and semi-diurnal tidal movements was got rid
while these differences themselves formed a basis of an indep
dent investigation of much interest. It was to the diurnal mo
ments, however, that his attention had been principally direct
By these movements the tidal range was affected sometimes
the extent of 6 feet, sometimes only a few inches, and th
variations had to be traced to their cause. These diurnal mo
ments had been termed "diurnal inequality" by the earli
authorities, and such attempts as had been made to predict th
were based on the principle of making additions and deductions
alternate semi-diurnal tides. But it was soon found to be impossib
to apply this principle in its simple form. The alternations h
periods of about a fortnight, and the number of such periods i
year agreed with the number of times that the moon crossed t
Equator, but the correspondence of individual periods of the ti
and astronomical facts followed some very complicated law wh
it seemed impracticable to formulate. The supposition, therefo
that the semi-diurnal tides were affected by some element which d
turbed alternate tides in opposite directions, both as regarded heig
and time, was abandoned; and it was assumed that the actual ti
movement consisted of a uniform series of semi-diurnal tides risi

and falling on a sea already under the influence of a diurnal tidal movement. The problem now was how to separate these two concurrent series of tides and exhibit them independently. After trial of several methods the following plan was found the most convenient: On the diagram which represented successive high waters and low waters, lines were drawn joining the alternate tides; then half the difference between any required high water and the line joining the high waters immediately before and after it would give the elevation or depression due at that time to the diurnal tide. Mr. Parke

Thus were obtained four values per day of the diurnal tide at approximate intervals of six hours, or of one-quarter of the tidal period. If the tidal period was represented by 360°, each of these intervals would be 90°. The elevation of the water at any moment, due to a tide, was represented by the half range of the tide multiplied by the cosine of the angle representing the interval of time between that moment and the time of high water or low water. If, then, R was taken to represent the half range of a diurnal tide, and t the interval between its time of high water and the time of one of the six-hourly values obtained from the diagram, there followed as an expression for that value

$$R \cos t.$$

But the expression for the next six-hourly value would be

$$R \cos (90^\circ - t), \text{ or } R \sin t;$$

from which two values, R and t, could be found.

Now it was evident that by taking the numerical values of a series of $R \cos t$, and $R \sin t$, a corresponding series of values for R and t might be found; and this gave, in fact, a complete register of the height and time of high and low water of diurnal tide, independent of the semi-diurnal movements. Such a register was made for the six months' Kurrachee observations of 1865, and for the twelve months' Bombay observations of 1846, and plotted as diagrams. The results were a series of curves exhibiting forms and periods which could hardly have been anticipated from those exhibited by the first diagrams of the combined semi-diurnal and diurnal tides. But when compared with the periods of the moon's movements, the coincidence was most marked. As the moon receded from the equator the diurnal tide increased, and as it approached the equator it diminished. It presented in a modified form the phases of neaps and springs, so marked in the semi-diurnal tides, the recurrence of these depending, of course, upon the sun's influence. But there was one very marked difference between the semi-

Mr. Parkes. diurnal and diurnal tides. The former consisted of the c
tion of a series of nearly equal lunar tides, having periods o
hours and about twenty minutes, with a series of nearl
solar tides having periods of twelve hours. The diurn
consisted of a series of lunar tides having periods of twe
hours and forty minutes, combined with a series of solar tides
periods of twenty-four hours; but these two series, instead o
as in the case of the semi-diurnals, equal from day to day, w
stantly varying, the lunar tides going through a cycle of
from zero to their maximum, and back to zero in a fortnigh
the moon was in north or south declination; while the sol
went through similar cycles, but in periods of half a year,
of half a month. Thus the changing values of the diurnal lu
tides followed laws of a much more complicated charact
those of the semi-diurnal tides, and it soon became evide
they could not be discussed on the system established by S
Lubbock, and followed by the Admiralty in respect of semi-
tides. The next step was, therefore, to devise a new me
discussion. The graphic system of delineation here became v
It exhibited at a glance the tidal changes, side by side w
changes of the positions of the sun and moon. By sele
number of cases where the sun's influence was known to b
the value of the moon's influence under the conditions at th
existing was determined; and by selecting other cases o
moon's influence, the value of the sun's influence could be si
determined. From the data thus obtained, expressions
solar and lunar tides, in terms of the positions of the s
moon, could be formed, and the combination of these for an
time would express the hypothetical state of the diurnal
that time. The recurring maximum and minimum values o
combinations represented the hypothetical diurnal high a
waters.

Such a hypothetical register was formed, and it was fo
give a very fair approximation to the register of diurnal t
deduced from observation. Then the hypothetical diurna
were combined with calculated semi-diurnal tides obtained
Admiralty system of prediction, and the result compared w
observations of actual tides. The coincidence was fair.
most important features were represented, even those wh
first had appeared most anomalous. There still remained
small discrepancies, the cause of which had not yet been
mined, but they were not of great importance. These result
obtained from the Kurrachee observations of six months in

Mr. Park

A series of complete tides was then calculated by the same formulæ and constants, for the time during which the observations were recorded in 1857–8, and the coincidence was found to be quite as good—95 per cent. of the predictions were within 5 inches of the recorded heights. By subsequent amendments of the constants, based on later observations, these proportions of error were reduced. In May and July 1866, he brought the results of his investigations into the tides of Kurrachee and Bombay respectively to the notice of the Secretary of State for India, and that Minister, after taking the opinion of the hydrographer of the Admiralty, gave instructions for the computation of Tide Tables for those ports for the following year; and the computation was continued by Government authority, under Mr. Parkes' directions, for twelve years afterwards. In 1880 Mr. Roberts' machine-computed Tables were for the first time issued for Bombay and Kurrachee, and for 1881 Tables for six other Indian ports had been added.

He had felt it right to present this brief account of his own labours in the cause of Indian tides. He had done so in no spirit of rivalry with the Author of the Paper. On the contrary, he was glad to hand over the conduct of the investigation of a subject in which he only claimed to have been the first to obtain practically useful results to such able hands. He believed, however, that the principles of his process were worth recording in the Minutes of Proceedings of the Institution, as an instance of the successful deduction of a result by the systematic analysis of a large number of facts.

Mr. Unwi

Mr. **Howard Unwin** remarked that some diagrams of the Hooghly river tides, forming part of a series of observations made by order of the Government of Bengal in 1872, had been taken to ascertain the passage of a cyclone wave up the river Hooghly.

Four self-registering machines were put up in a distance of about 80 miles. They were supplied by Messrs. Elliott, and were of the ordinary pattern, fitted with eight-day clocks. The barrel was horizontal, 12 inches long, 8 inches in diameter, the scale being ½ inch to 1 foot for height of tide, and the hour lines at intervals of 1 inch, the barrel making a complete revolution in the twenty-four hours. The pencil was carried in a slide worked by a chain and wheel from a copper float 10 inches in diameter, 12 inches deep, the weight of chain being counterbalanced by a strong spiral spring in the usual manner. The float worked in a wooden trunk, and the pencil made a distinct clear line except in very rough weather, and especially at low water, when the

. Unwin. oscillations of the pencil gave a shaded line from $\frac{1}{8}$ inch to $\frac{1}{16}$ inch broad.

Each machine was in charge of a native observer, who change the barrel every eight or ten days. The observations had bee kept up to the present time, and some remarkable curves had bee produced on the occasion of a cyclone or from bad weather; copie of them could be obtained from the Indian Government.

The machines were not absolutely accurate, but quite sufficien for the purpose. Similar machines, only larger and of bette construction, were now used by the Trigonometrical Departmen (Survey), to determine the mean sea level, under Captain Baird' superintendence.

There was no doubt that the new machine described in th Paper had many advantages and improvements, but its cost mu be much greater, and this in some cases might prevent i adoption.

8 and 15 March, 1881.

JAMES ABERNETHY, F.R.S.E., President,
in the Chair.

The discussion upon Sir William Thomson's Paper on "T Tide Gauge, Tidal Harmonic Analyser, and Tide Predicte occupied both evenings.

22 March, 1881.

JAMES ABERNETHY, F.R.S.E., President,
in the Chair.

(*Paper No. 1768.*)

"On the Comparative Endurance of Iron and Mild Steel when exposed to Corrosive Influences."

By David Phillips, M. Inst. C.E.

Iron and so-called mild steel have been subjected from time to time to such elaborate mechanical tests, at the hands of so many practical men, as to render further investigation into their comparative strength and ductility almost unnecessary; but the endurance of these metals when exposed to corrosive influences, a subject scarcely second in importance to that of their strength, has been almost entirely neglected. Excepting the work of the late[1] and the present[2] Boiler Committees of the Admiralty, and of some government officers, there are, the Author believes, the results of only a very few experiments on record.

Having regard to the numerous discussions which have taken place during the last three years respecting the materials best suited for the construction of ships, boilers, and bridges, and remembering the efforts that have been made to perfect mild steel for those purposes, it is extraordinary that the subject should have received so little attention. Even the opinions advanced by experts are conspicuous by their lack of reliable information, opinions emanating nevertheless from those who would doubtless be able to give valuable information were the question fairly treated. But recent discussions, the Author thinks, have afforded evidence of partiality, mild steel finding advocates in abundance, while the question of its endurance when exposed to corrosive influences, as compared with iron, appears, from the consumer's point of view, to have been purposely neglected.

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[1] *Vide* "Reports of the Committee appointed by the Admiralty to inquire into the Causes of the Deterioration of Boilers, &c., with Appendices and Minutes of Evidence." 2 vols. Folio. London, 1877.

[2] *Vide* "Report of the Committee appointed by the Admiralty to continue and complete the inquiry into the Causes of the Deterioration of Boilers, &c." Folio. London, 1880.

The Author had the honour to serve on the Committee appointed by the Admiralty in June 1874 to inquire into the causes of corrosion in boilers, and since its dissolution he has made further experiments with the same objects in view. He trusts that his efforts to throw light on the matter may be of advantage to the profession. It will be necessary for the purpose he has in view to refer to several of the experiments made by the late Boiler Committee, as well as to his own; and it may be remarked in passing that it would have been satisfactory to all interested in engineering matters, had the results of the last twelve months of the labours of the Committee, and of the experiments continued at Devonport after its dissolution, been published before this.

In this Paper it is proposed to treat chiefly of the comparative durability of iron and mild steel when exposed to similar influences. The action on these metals of various kinds of water in the presence or absence of air, alkalies, &c., is too wide a subject to include, even if it had not already been treated by the Chairman of the late Boiler Committee, Rear-Admiral C. Murray Aynsley, C.B.[1]

The first experiment to be mentioned is that referred to in the third report of the late Committee, p. xi. Six sets of tubes of different brands of iron and steel, prepared for the purpose, were tested in a special apparatus in Sheerness dockyard, with the view of ascertaining their comparative durability. The sets were numbered from 1 to 6, but as some of the tubes became unfit for testing, sets 1 and 6 will be only incidentally referred to. The remaining four sets consisted severally of tubes of one of each of the following brands, viz.:—

A.I.	Lloyd and Lloyd's improved metal (iron).
B.W.	Whitworth's compressed steel.
B.F.	Fagersta Bessemer steel.
C.	Bolton Iron and Steel Co.'s Bessemer steel.
D.	Crampton's thrice hammered iron.
E.	Lloyd and Lloyd's improved homogeneous metal (iron).
F.F.	Firth and Sons' crucible steel.
F.S.	Ordinary iron (not specially prepared).
G.	Cammell and Co.'s special steel.

Sets 2 and 3 had each in addition a Yorkshire iron tube (A.Y. 15 and 19) thus making the total number of tubes thirty-eight, eighteen being of iron and twenty of steel. The Whitworth,

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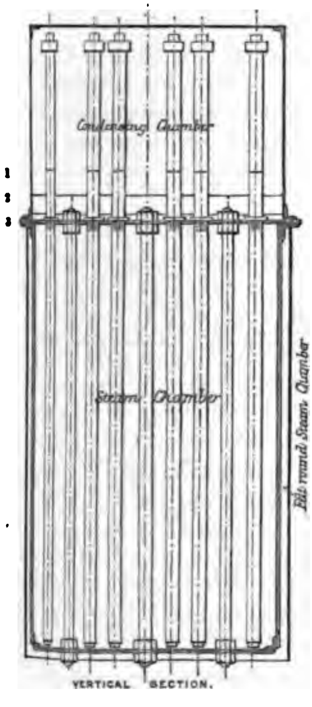
[1] *Vide* Journal of the Royal United Service Institution, vol. xxiv., p. 259.

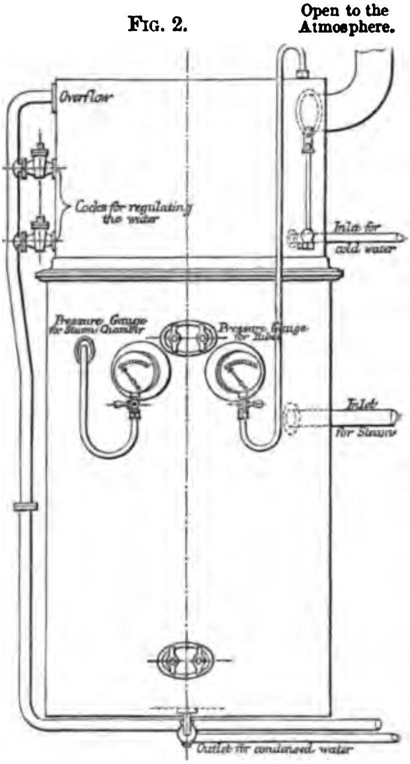
Fagersta, and Firth's steel, and the Crampton iron tubes, were cold-drawn; the others were welded. The cold-drawn tubes had originally a smooth and clean surface, with only a film of oxide, the result of annealing, whilst the welded tubes, especially those of iron, were rather rough, with the usual coating of oxide. This would be in favour of the steels in calculating the losses of weight. All the tubes were carefully weighed before and after each experiment, and were 8 feet in length and 2½ inches in diameter, representing an exposed surface inside and out of 9·58 square feet, with the exception of the ordinary iron tubes (Fs), which were 2 inches in diameter, and had 7·68 square feet of exposed surface.

Fig. 1.


1
2
3
Condensing Chamber
Steam Chamber
Felt round Steam Chamber
VERTICAL SECTION.

Vertical Section.

Fig. 2.


Open to the Atmosphere.
Overflow
Cocks for regulating the water
Inlet for cold water
Pressure Gauge for Steam Chamber
Pressure Gauge for Tubes
Inlet for Steam
Outlet for condensed water

Front Elevation.

Scale ⅜ inch = 1 foot.

¹ Level of water in tubes.
² Level of water in condensing chamber.
³ Non-conducting material (putty.)

The testing apparatus consisted of two cylinders, 3 feet 7 inches in diameter and 6 feet in height, as shown in Figs. 1 and 2, the tubes being screwed tightly through the top ends. The parts of the tubes, 5 feet 8 inches in length, thus confined cylinders and filled with various kinds of water, were e during the working hours in the yard to an average steam sure of 50 lbs. per square inch, the steam being supplied fr of the factory boilers close by; whilst the upper parts, rep ing, as it were, the steam spaces of boilers, were inclose chamber open to the air, and supplied with sufficient cold w ensure partial condensation of the steam within. The a steam pressure in the tubes was thus kept at about 38 l square inch.

The following were the conditions of working, and the lo weight of the tubes after a little more than two years' trial

TABLE I.

—	Kind of Water, Alkali, &c., in Tubes.				Loss of Weight.			
	Set 2. $\frac{1}{32}$ Density and 500 grs. of Lime; Air admitted Weekly.	Set 3. Sheerness Well, no Alkali; Air admitted Weekly.	Set 4. Rain, and 500 grs. of Soda; Air excluded.	Set 5. Distilled from Sea Water, no Alkali, Air excluded.				
Tubes.	Loss of Weight.	Loss of Weight.	Loss of Weight.	Loss of Weight.	Total Loss of Weight.	Mean Loss per Tube.	Average Loss per Sq. Ft. of Surface.	A L Sc S
	Oz.	Oz.	Oz.	Oz.	Oz.	Oz.	Oz.	
Steel B.W.	21·25	28·00	20·25	11·25	80·75	20·19	2·1072	
„ B.F.	24·00	27·25	15·75	12·50	79·50	19·87	2·0746	
„ C. .	23·75	23·00	22·00	13·25	82·00	20·50	2·1398	
„ F.F.	21·25	16·50	17·00	18·25	73·00	18·25	1·9050	
„ G. .	20·25	16·25	18·75	16·50	71·75	17·94	1·8723	
Total loss	110·50	111·00	93·75	71·75	387·00	..	..	169
Mean loss	22·10	22·20	18·75	14·33	19·35	..	2·0197	
Iron A.I. .	12·75	11·75	14·50	13·25	52·25	13·06	1·3635	
„ D. .	15·50	16·00	17·25	12·25	61·00	15·25	1·5918	
„ E. .	14·00	17·25	25·25	12·00	68·50	17·12	1·7876	
„ F.S. .	6·00	7·00	5·00	3·75	22·25	5·56	0·7113	
„ A.Y.	14·25	11·50	..	..	25·75	12·87	1·3440	
Total loss	62·50	63·50	62·50	41·25	229·75	..	..	100
Mean loss	12·50	12·70	15·62	10·31	12·77	..	1·3890	

Taking all the four sets, representing 191·6 square feet of steel, and 165·4 square feet of iron, the results are as follow:—

TABLE II.

Number of Tubes.	Metal.	Total Loss of Weight.	Average Loss per Square Foot of Surface.	Percentage in Favour of the Irons.
		Oz.	Grs.	
20	Steels	387·00	883·66	45·4
18	Irons	229·75	607·71	

Taking sets 2 and 3 only, representing 95·8 square feet of steel and 92·28 square feet of iron, the following is the result:—

TABLE III.

Number of Tubes.	Metal.	Total Loss of Weight.	Average Loss per Square Foot of Surface.	Percentage in Favour of the Irons.
		Oz.	Grs.	
10	Steels	221·5	1,010·50	69·2
10	Irons	126·0	597·36	

The tubes in each set were under precisely similar treatment; consequently the loss of weight of each of the different brands is a fair criterion of their comparative durability.

Illustrations are exhibited of gutta-percha impressions taken from parts of some of the tubes at different levels. They give a fair idea of the nature, as well as of the severity, of the corrosion. The specimens are arranged in order, according to the severity of the corrosion, as deduced from the examination of their interior surfaces, but in weight the ordinary iron lost the least, and the Fagersta and the Whitworth steels the most; and they represent respectively set 2; the exterior surface at about the water-level in the condensing chamber, the interior surface in the steam space, at the water-level, and the bottom ends of the tubes. The Barrow steel tubes H 2 and 3 were tested only half as long as the others; taking this into account, it will be seen by the impressions that the corrosion was exceptionally severe. The group marked A and G represents set 4; and that marked Fs and Bw, set 5. The A and Fs were the least, and the G and Bw the most affected of the two last sets, which compare favourably with sets 2 and 3. The impressions in the centre of the top row were taken from the interior surfaces of the AY and I tubes at the water-line and at the bottom ends. Only two of these tubes, 15 and 19, were under similar conditions to sets 2 and 3, and are included in the four sets before mentioned.

Small disks of iron and steel of various brands were also tested in another group of tubes in the apparatus. Impressions taken from these, and from some pieces of the same metals, which were tried in boilers at Devonport, are likewise illustrated. Full particulars of these experiments will be found in the third report of the Committee, appendices G and H, pp. 267–268 and 281–284.

All the specimens, tried in boilers, from which the impressions were taken, had originally bright surfaces. The top row represents the disks in contact with zinc; the second row those with no zinc present.

There was a striking difference between the iron and steel disks, and also between the several steels as regards the nature and severity of the corrosion. While the disk O (steel) was very uniformly affected, the disk V was deeply pitted; yet the loss of weight in the latter was 19 grains less than in the former. The O 2 from the same plate as the O disk was much rougher, while the loss of weight was 18·8 grains less. The A disk (steel) was peculiarly affected, being pitted in small deep holes, whilst the intervening surface was scarcely touched. Again, the edges of some of the disks were corroded uniformly, whilst others were affected in a most extraordinary manner, especially the R, A, and Y steel disks. The edges of the Y iron disks were corroded in ridges and grooves, showing plainly that the bloom had been made up by ordinary piling, and that the piles could not have been of uniform quality.

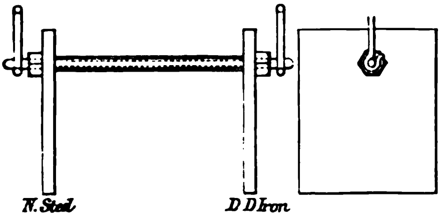
The metals in this experiment were doubtless exposed to a severe test. They were suspended in copper tubes, filled with water of $\frac{2}{32}$ density, with tallow as a lubricant, air being admitted weekly. The duration of the experiment was six months only.

Impressions taken from pieces of iron and steel of various brands, which were suspended for twelve months in one of the boilers of the "Trusty," a tug having a jet condenser, and worked at a low pressure, are also shown. The bottom row represents the set that was in the water, and the other the duplicate set that was in the steam space. These pieces were cut from plates which were subjected to cold bending and other tests, as described in the Reports of the Boiler Committee. Excepting the edges, the surfaces were rough. The Whitworth compressed and the Siemens steels were not included in this group, on account of the delay in their production. In this experiment again, the loss of weight in the steels and the nature of the oxidation were remarkable. The percentage in favour of the irons was 32·7; in the disk experiment it was 56·7.

The same set of plates, with others of Whitworth's, Siemens', and Attwood's steels added, were tried for another twelve months in a feed-water heater supplied with fresh water, and a duplicate set in one of the boilers of the "Perseverance," a tug worked at a low pressure and fitted with surface condensers. The surfaces of the specimens had all been made bright. The percentage in favour of the irons was 27·5 in the tug, and 11·8 in the feed-water heater. The pieces of metal tested in these experiments were very small, but the results are not without significance.

Plates of Bolton steel and Lowmoor iron, 10 inches long by 8 inches wide by $\frac{9}{16}$ and $\frac{7}{16}$ inch thick respectively, were also placed in the boilers of the two tugs before mentioned. They were suspended as shown in Fig. 3, with the view of ascertaining the comparative effects of fastening together plates of steel and iron with brass and with iron stay; and also the action of zinc on two plates, steel and iron, connected together, when attached to only one of them. Eight plates of each metal, representing 9·9 square feet of steel and 9·68 square feet of iron, were tested. The result from one-half of the specimens after thirteen months' trial was as follows:—

FIG. 3.



Scale 1 inch=1 foot.

TABLE IV.

Number of Plates.	Metal.	Total Loss of Weight.	Average Loss per Square Foot of Surface.	Percentage in Favour of the Irons.
		Oz. Grs.	Grs.	
4	Steels	7 209·3	659·63	32·7
4	Irons	5 218·7	497·14	

The corrosion in the steel plates, in the form of "pitting," was so marked, and the difference between the plates from the "Trusty" and from the "Perseverance" so great, that all these eight plates were forwarded to the Admiralty for inspection. The result of the trial of the other eight, four for twenty-one and four for twenty-two months, was as follows:—

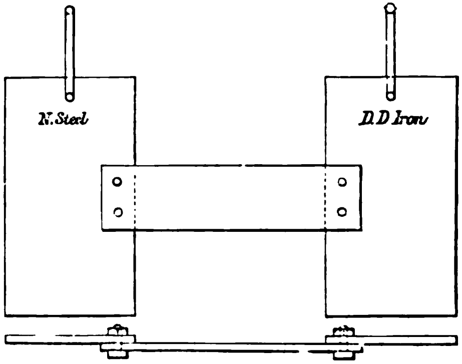
TABLE V.

Number of Plates.	Metal.	Total Loss of Weight.		Average Loss per Square Foot of Surface.	Percentage in Favour of the Irons.
		Oz.	Grs.	Grs.	
4	Steels	10	382·9	959·25	28·6
4	Irons	8	109·4	745·74	

The impressions taken from one-half of these plates, though slightly distorted, give a fair idea of the corrosion sustained by the two metals. N 5 was taken from one of the steel, and D D 6 from one of the iron plates.

Plates of the same metals, 15 inches long by 8 inches wide by ½ inch and ⅜ inch thick respectively, were also tested in the feed-water heater before mentioned. They were suspended as shown in Fig. 4.

FIG. 4.



Scale 1 inch = 1 foot.

The result after thirteen months was:—

TABLE VI.

Number of Plates.	Metal.	Total Loss of Weight.		Average Loss per Square Foot of Surface.	Percentage in Favour of the Irons.
		Oz.	Grs.	Grs.	
2	Steels	19	327·9	2,453·9	10·9
2	Irons	17	218·7	2,212·2	

The impressions were only taken from a part of each of the plates in consequence of their size; but they show fairly well the nature of the extraordinary corrosion which occurred. The corrosion in the steel plates was only a little more marked and irregular than in the iron. Impressions 5 and 6 were taken from the tieplate, and 7 and 8 from the shell of a small steel boiler doing harbour duty at Chatham, which show very deep pitting. One group of impressions represents plates of Lowmoor iron and of Landore steel, 4 inches square by $\frac{3}{8}$ inch thick, which were suspended in pairs in vessels under slightly different conditions for a period of six months. Those marked 3 were in the same feed-water heater as the last-named plates. The result was:—

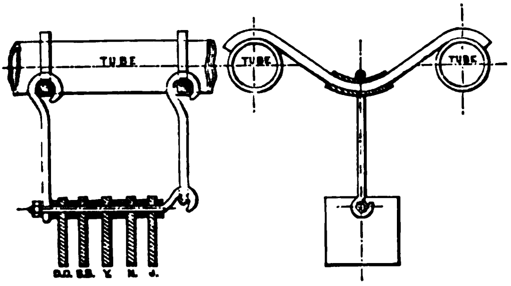
TABLE VII.

Number of Plates.	Metal.	Total Loss of Weight.	Average Loss per Square Foot of Surface.	Percentage in Favour of the Irons.
		Oz. Grs.	Grs.	
4	Steels	1 85·0	506·24	4·8 nearly.
4	Irons	1 73·5	483·17	

The only peculiarity worth noticing in this experiment is that, while the two plates in the feed-water heater lost 381·8 and 394·2 grains, the two in the boiler fed from the heater lost only 8·0 and 3·4 grains respectively. In a former experiment, when iron only was placed in the feed-heater and boiler in question, the plate in the heater lost 405 grains, whilst that in the boiler lost during thirteen months only 20 grains. The heater was an open vessel, and the boiler was worked at a pressure of about 55 lbs. to the square inch.

The next experiments to be mentioned are a series made with ron and steel plates, 4 inches square by $\frac{3}{8}$ inch thick, suspended ı the boilers of different ocean and coast-going steam vessels elonging to various shipowners, as shown in Fig. 5.

FIG. 5.



Scale 1 inch = 1 foot.

The results are interesting from more points of view than one; but in this Paper they will be treated chiefly as affecting the subject under consideration, the effects of the different treatments they experienced having been already dealt with by Admiral Aynsley. However different the treatments, and whatever the effects, it should be remembered that the five plates, all of different metals, of which each set consisted, were always under precisely similar conditions, whether in or out of the boiler. The exposed surface of each plate was 37·89 square inches, and the aggregate surface of each kind of metal in the fifty-six sets which have come under the Author's notice was 14·74 square feet, or 44·22 square feet of steels, and 29·48 square feet of irons. The five metals were crucible, Bessemer, and Siemens steels, and B B Staffordshire and best Yorkshire irons. The periods of trial varied from five months to two and a half years.

The gross results are given in the following Table:—

TABLE VIII.

Number of Plates.	Metal.		Total Loss of Weight.		Average Loss per Square Foot of Surface.	Percentage in Favour of the Irons.
			Oz.	Grs.	Grs.	
56	J.	Crucible steel .	97	70·8	2,885·83	14·3 good.
56	N.	Bessemer " .	118	229·4	3,520·32	Or over.
56	Y.	Siemens " .	116	166·8	3,456·67	N and Y only (mild steels).
56	B.B.	Staffordshire iron	92	163·0	2,743·58	21·3 good.
56	D.D.	Yorkshire "	101	115·7	3,007·68	..

The impressions taken from a few of these sets are shown, and are interesting as illustrating the character of the corrosion caused by a change of conditions, such as the waters used, different practices of blowing-off, &c., as well as the comparative effects on the different metals.

To venture a little beyond the subject of the Paper, it may be observed that the difference in the condition of some of the sets is remarkable. For example, in sets 2 and 43 the character of the corrosion, was quite different; and whilst the mean loss of weight of set 43, after being in the boiler two hundred and eighty-five days, was 347·7 grains, that of 2, after being in the boiler three hundred and eleven days, was 825·4 grains, or per day as 1 to 2·1.

The boiler in which set 43 was suspended was filled fourteen times with fresh water, 2 inches of water being blown off daily, whilst that in which set 2 was hung was filled eight times with fresh and five times with sea water, 3 inches of water being blown off daily at sea and 12 inches at intermediate ports.

A limited quantity of zinc was certainly present, though only suspended loosely, in the boiler with set 43, and to this its better condition may perhaps be attributed; but on comparing set 62 with 43, it would appear that the zinc had no influence on the plates.

Boiler 62 was employed in the same trade as boiler 2, namely, India and China. The plates were in the boiler two hundred and ninety-eight days, during which period it was filled five times with fresh water, 1 inch being blown off daily, and no zinc present, yet the mean loss of weight was only 364·9 grains as compared with 825·4 grains in set 2; or per day as 1 to 2·1.

Again, comparing set 84 with 62, the bad effects of much blowing-off are manifested. Set 84 was only forty-three days in the boiler, which was filled during that period four times with sea and once with fresh water, whilst, extraordinary as it may seem, an average of 73 inches of water was blown off daily. This, with the waste from other sources, was made up from the sea. The mean loss of weight in this set was 575·7 grains, as against 364·9 grains in set 62, being at the rate, per month of thirty days, of 401·7 grains in the former against 36·7 grains in the latter, or nearly twelve times as much.

As the boilers in these cases were fed from surface condensers and worked at a high pressure, it may be of interest to compare the results with those obtained from two jet-condensing low-pressure boilers, though this type is almost a thing of the past. Referring then to set 9, and set 63, the mean loss in each was practically the same, viz., 1,332 and 1,333·8 grains. Set 63 was one hundred and seventy-four days in the boiler; there is no record of the time that set 9 was in the boiler, but the total time was nearly the same as for the former set.

Comparing these results with those obtained from set 2, which was subject to the old, or perhaps the ordinary surface-condensing reatment, the loss from corrosion was nearly three times as much n the jet-condensing boilers, or per day as 2·8 to 1. Again, omparing these two sets, 9 and 63, with set 62, which was sub- cted to something like the most improved method of working, e loss in the jet-condensing boilers was about six times that in e boiler with surface-condensers, namely a mean loss of 1,332·9 ains as compared with 364·9 grains, or per day as 6·2 to 1.

TABLE IX.

Number of Set.	Metal.	Water.	Loss of Weight.				Percentag Favour of
			First Twelve Months.	Second Twelve Months.	Total.	Average per Sq. Ft. of Surface.	
			Grs.	Grs.	Grs.	Grs.	
98	N. Bessemer steel.	Rain water.	186·7	141·4	328·1	1,246·9	Irons = including 9·4 ne
	Y. Siemens steel.		174·1	147·0	321·1	1,220·3	
	B.B. Staffordshire iron		165·3	119·0	284·3	1,080·5	
	D.D. Yorkshire iron.		185·1	136·2	321·3	1,221·1	
99	N. Bessemer steel.	Sea water.	42·4	36·9	79·3	301·4	Irons =
	Y. Siemens steel.		33·5	34·7	68·2	259·2	
	B.B. Staffordshire iron		35·4	35·6	71·0	269·8	
	D.D. Yorkshire iron.		36·9	31·6	68·5	260·3	
100	N. Bessemer steel.	Exposed to the weather and dipped in sea water daily.	1,044·7	501·6	1,545·6	5,874·0	Iron =
	B.B. Staffordshire iron		417·9	259·1	677·0	2,572·9	
	Y. Siemens steel.	Exposed to the weather only.	234·4	135·9	370·3	1,407·3	Iron =
	D.D. Yorkshire iron.		147·6	52·7	200·0	761·2	
101	N. Bessemer steel.	Exposed to the weather, and dipped in fresh water daily.	227·9	..	..	866·1	Iron =
	B.B. Staffordshire iron		84·5	..	..	321·1	
	Y. Siemens steel.	In kitchen tank along with J. 99.	134·5	..	..	511·2	Iron : go
	D.D. Yorkshire iron.		125·2	..	..	475·8	
102	N. Bessemer steel.	Rain water direct from the clouds, filtered	28·5	..	..	108·3	Steels :
	Y. Siemens steel.		28·8	..	..	109·5	
	B.B. Staffordshire iron		30·7	..	..	116·7	
	D.D. Yorkshire iron[1].		38·1	..	..	144·8	
[2]98	J. Crucible steel[2].	Rain in water-butt.	198·4	146·2	344·6	1,309·6	99 ov = 2
99	J Crucible steel.	Same water in kitchen tank.	166·3	119·8	286·1	1,087·3	100 o = 52·1
100	J. Crucible steel.	Same water in kitchen boiler.	118·9	107·6	226·5	860·8	100 o = 26·

[1] Cinder removed after the plate was weighed and included in the loss given.

[2] Co

o the appearance of ces before Testing.	Remarks on the appearance of the Surfaces after Testing.
d bright all over	Slightly pitted in small spots, and corroded in large patches, the Y. being the least and more generally corroded of the two, but not very much discoloured.
ty on one face .	Less affected, and more generally of any of the set.
dirty on both (cinder) . . .	Much the same as Y., but more generally affected of the two, and only slightly discoloured.
d bright all over	Scarcely at all affected, except at top corners, which are black; the Y. is slightly touched under the hole on one face; both are nearly bright otherwise.
ty on one face . dirty on both (cinder) . . .	Top corners of both black; one face of the B.B. slightly touched under the hole; crystalline appearance, but finer than D.D.; otherwise both appear dirty.
ll over . . .	Very rough and deeply marked all over.
y dirty . . .	Very much less marked; no comparison between the two.
ll over . . . y dirty all over .	Slightly marked all over, the Y. being more affected under the hole on both sides; generally the difference is not much.
ll over . . . ce very dirty; the better . . .	Marked all over; slight at top, increasing in severity downwards in both; but much more severe in N. than B.B.; the latter has a few very minute bright specks on one face after cleaning (something like minute blisters).
ll over . . . ce very dirty; the r one half only .	Corroded in patches, which are very local in both; nearly half the surface scarcely at all affected. Slightly more locally affected and marked in the Y., but very similar to the J. 99 after twelve months' trial.
t all over . . .	Very slightly affected along the top edges, the corners are black, the rest being nearly bright.
lirty all over; la- ted in one corner. face slightly dirty; other very dirty. ler picked out and ression taken of it	These are a little more marked, due no doubt to cinder; surface generally crystalline, the B.B. having bright spots much more prominent than 99, projecting in the form of minute blisters above the surface.
all over . . .	Corroded similarly to N. and Y. 98, but slightly more marked.
	Similarly affected to the last, but a little more local.
	Generally unaffected, but black, with small patches of pitting, and pin-holes here and there. Bottom edge on both sides severely affected for ¾ inch up, with a few deep pit-holes on edges.

ther 98 specimens.

These results clearly prove that the conclusions arrived at by many experienced engineers and chemists as to the causes of corrosion in boilers, previous to the appointment of the Boiler Committee, were erroneous; but the conclusions are nevertheless still believed in to some extent, and the mode of working consequent thereon followed.

The Author will now describe the experiments he made with five sets of plates similar to those tested in ocean steamers. The conditions to which some of these plates were subjected, and the results obtained, are scarcely, if at all, less important than those of the experiments last described. They are given in Table IX. (see pages 84 and 85). To avoid even a suspicion that galvanic action had any influence in these cases, all the plates were suspended on glass rods, and each plate was separated from its neighbours by glass ferrules. Sets 98, 99, and 100 were under test for two years; sets 101 and 102 for only half that period. During the first twelve months set 98 lost considerably more than 99, and as this might have been due to the action of soot brought down from the roof, or of the lead of the water-butt, or both, set 102 was suspended in an earthenware pan similar to that containing 99, but filled with rain water direct from the clouds, and filtered.

Taking the aggregate losses of the irons and steels, omitting the crucible steel, the result was as follows:—

TABLE X.

Number of Plates.	Metal.	Total Loss of Weight. Oz.	Total Loss of Weight. Grs.	Average Loss per Square Foot of Surface. Grs.	Percentage in Favour of the Irons.
10	Steels	7	69·8	1190·41	64·8 nearly.
10	Irons	4	150·6	722·42	

Impressions taken from these sets of plates, after twelve months' exposure, and at the end of two years, are shown. There is little to remark concerning the results, except that the corrosion is strikingly local and severe in set 98, which was placed in rain water; also that wetting the metals daily, especially with sea water, and exposing them to the weather, causes very severe corrosion, which the irons, as shown by the Table, resisted much better than the steels.

The crucible steels illustrate further the action on metals of the same sort of water under slightly different conditions:—The specimen J 98 was in a butt which received water direct from the roof, 99 was in a small tank in the kitchen, supplied by hand with water from the butt, and 100 in a small boiler supplied with water from the tank, for culinary purposes.

In years gone by the rapid and sometimes sudden deterioration of boilers was attributed to galvanic action, supposed to be set up between the copper or brass tubes of the condensers and the iron of the boilers. Although this theory may be regarded as obsolete, others equally speculative have taken its place. Galvanic action is now said to be set up between steel and steel, or iron and iron, if they differ in the slightest degree in composition; between metals and the cinders too frequently found unfortunately pressed into them by the rolls; but especially between iron and steel, and between the metals composing boilers and the oxides with which they are coated. The galvanometer is a very sensitive instrument, and would, no doubt, show whether one metal were negative to another, or whether such differences existed between metals and their oxides as would produce galvanic action; but practically these theories are in the Author's opinion unworthy of much consideration. They are advanced by the ardent advocates of mild steel, and, as the Author thinks, are only a cloak to cover the too indiscriminate advocacy of that material.

It is easy to say that the purer classes of metals ought to offer greater resistance to corrosion than the impure kinds. Accepting the theories advanced by the advocates of mild steel, this is undoubtedly a necessary conclusion; for all classes of iron, and especially the commoner brands, have invariably a thicker coating of oxide than the steels, and moreover have the great drawbacks, cinders and laminations, which it is professed are unknown in steel. But in spite of these reasonings, it is undoubtedly a fact, that under almost all circumstances iron, and particularly the harder classes, is far superior to the finer steels in its resistance to corrosion, and this the experiments described by the Author incontestably prove.

As regards uniformity of composition, and temper also, steel has probably more than its fair share of praise. Laminations and cinders are undoubtedly the great objection to iron as now made, and this is well illustrated in the Cy group of impressions taken from one of the tubes tested. The centre impression shows the inner layer of a blister corroded through, and a large cavity thus formed in the tube; the one just above shows a blister punctured by a sharp-pointed instrument, while that below shows blisters untouched. It will be seen from these how easily original defects in the manufacture of tubes or plates, such as cinder, may be mistaken for what is called "pitting."

In these respects mild steel is no doubt much superior to iron, but that it is not without original defects, such as want of homogeneity and uniformity of temper, will be seen from another series of impressions. Here in some of the Y and J plates, there was to all appearance a small hard spot, which seems like a small pit surrounded by a slight ring. It should be borne in mind that these marks in the impressions appear the reverse of reality, the pits being spots much less acted upon, and the rings surrounding them grooves much more acted upon, than the rest of the surface of the plates.

Another plate (also Y), placed in the feed-water heater before referred to, had a spot, about $\frac{3}{8}$ inch in diameter, untouched by corrosion. After the plate had been six months under water the spot was quite bright, had its edge well defined, and was surrounded by a very slight groove; but the corrosion generally was trifling in this plate.

Some of the steel disks and tubes, especially the Whitworth's and Firth's, presented after testing a damaskeen appearance, being marked, very similarly to gun-barrels, with slightly and beautifully formed ridges and grooves.

Want of uniformity on the part of the steels will also be seen in Table 1 in the Appendix, giving the results of the cold-bending test of the metals tested in the tube apparatus. Although three out of the five brands of steel had stood the severe test of being drawn cold from blooms with only a small hole drilled through the centre, there were surprising differences of temper, not only between the various brands, but also between the different tubes of each brand. Some of them, especially the Firth's, Barrow and Whitworth's, split up in various directions, and broke in several pieces whilst going through the ordeal of cutting open longitudinally, for the inspection of their interior surfaces, whilst others of the same brands showed scarcely any distress. It was on account of this that strips were cut from the tubes and subjected to the tempering test.

On comparing also the behaviour of the tempered with that of the annealed specimens under the cold bending test, the results are unsatisfactory. For whilst three of the metals after annealing were bent, doubled, and then hammered flat, without exhibiting any but the slightest signs of distress, after tempering the same metals only stood bending to the following angles before showing distress, viz., four strips from the Bf tubes to 35°, 34°, 11°, and 5°, the last two then breaking; three strips from the C tubes to 74°, 72°, and 36°; and four from the Ff tubes to 12°, 11°, 9°, and 0°, the last breaking suddenly.

The other three steels stood the test as follows, after annealing. The G steel was bent to a semicircle at the crown of ½-inch in diameter, when half of it broke through, the other half remaining perfect. The Bw was bent to an angle of 147°, when it began to yield in the centre of the crown, the edges being perfect. The H was bent to a semicircle $\frac{5}{16}$ inch in diameter at the crown, when it broke half through. After tempering, the same metals only stood bending as follows:—Five Bw strips to 11°, 8°, 6°, 4°, and 0°, all being broken through; four G strips to 40°, 16°, 0°, and 0°, the last two breaking suddenly. The two H strips also broke without bending.

Of all the six brands, the Bw were the most uniform in temper and in grain of fracture, though hard; the C being the softest, while the Bf, Ff and G showed the greatest contrasts, especially in the appearance of their fractures. The Bf and Ff varied from fine to very coarse in grain, one edge of each being much coarser than the other. One of the G's was ductile and the fracture rather silky in appearance, the next was hard and fine in grain, the third hard but coarse in grain, and the fourth fine and silky at both edges, but laminated and dirty in the centre. The annealed strip of the G was also remarkable; for, while it broke through halfway across long before the crown was hammered flat, the other half showed no signs of distress. In another case a strip of Bf broke after bending to 34°, when it exhibited a very coarse fracture; a second strip, cut from the same tube, bent only to 18°, and showed a fine steely fracture. It is certainly possible that these great contrasts may to some extent be due to want of care in the manipulation of the metals, and not entirely to want of uniformity in their composition; but it must be admitted, on the other hand, that such metals as will harden considerably when only moderately heated and plunged into water of ordinary temperature, are unfit for boilers, especially for furnaces and combustion chambers. It should also be remembered that the tubes in question were made specially for testing, and it is therefore fair to suppose that more than ordinary care was taken to supply good material. In that case, what could be expected from tubes or plates supplied wholesale?

It is important to ascertain how far want of uniformity in composition has to do with local corrosion in metals, and particularly in steel; also how far the presence in a medium degree, or absence in a minimum degree, of impurities in iron and steel can affect their durability.

It may be observed that local corrosion cannot have been caused in any of the specimens of metals dealt with in this Paper by the imperfect adhesion of their oxides, as, with the exception of the small pieces of plates tried in the "Trusty," and the welded tubes, all the specimens were either planed, filed, or ground bright all over.

It has often struck the Author that the manufacturer and the chemist, in their anxiety to produce a metal containing the least possible amount of impurities, and thus to attain a high standard of ductility, in depriving it, perhaps to a greater degree than necessary, of elements such as phosphorus, carbon, &c., or adding to it manganese, probably thus render it more liable to corrosion. If the metals tested in sea-going boilers be compared (the results are given in Table VIII.), it will be found that the ordinary BB Staffordshire iron has a percentage in its favour of 9·6 over the best Yorkshire iron, and that the harder steel, J, is 20·9 per cent. better than the two mild steels N and Y. Comparing the two irons with the two mild steels there is a difference of 21·3 per cent. in favour of the irons. On the other hand, it should be mentioned that in one or two cases the harder metals suffered considerably more than the softer metals in sea water; but generally the reverse was the case. In the irons laminations and cinder no doubt caused these exceptions, but in the steels they were in all likelihood due to want of homogeneity.

It will not be out of place to give the results of the trial of three of these sets of plates to show how great the differences were between the loss sustained by one or more of the metals compared with others of the same set (see Table XI., p. 91).

The 31st set of plates was in one of the boilers of the "Duke of Sutherland," a Holyhead boat belonging to the London and North Western Railway Company; the time occupied was the longest of all the ocean experiments, namely, two and a half years. This vessel has two iron and two steel boilers; and as they are about five years old, and as the steel was manufactured at the Company's works at Crewe, it would be interesting to know how the steel boilers now compare with the iron boilers.

In set 78 the Yorkshire iron DD shows a loss a little over twice that of the hard steel J; but in this instance the iron indicated plainly that a thin layer at the edge of one side, no doubt the result of lamination, had got disengaged, or corroded through.

Again, in set 91 the hard steel J lost nearly 35 per cent. more than the mild steel N, and the soft iron DD lost 26·3 per cent. more than the hard iron BB.

TABLE XI.

Number of Sets.	Letter Marked with, and Kind of Metal.	Total Loss of Weight.	Average Loss per Square Foot of Surface.	Percentage in Favour of the—
		Grs.	Grs.	
31	J. Crucible steel .	2,027·5	7,704·5	Irons = 104·3
„	N. Bessemer „ .	2,630·2	9,994·7	
„	Y. Siemens „ .	2,437·3	9,261·7	
„	B.B. Staffordshire iron	1,085·0	4,123·0	
„	D.D. Yorkshire „	1,230·1	4,674·3	
78	J. Crucible steel .	657·9	2,500·0	Steels = 51·4
„	N. Bessemer „ .	839·4	3,189·7	
„	Y. Siemens „ .	718·1	2,728·7	
„	B.B. Staffordshire iron	891·6	3,388·0	
„	D.D. Yorkshire „	1,344·6	5,109·4	
91	J. Crucible steel	124·5	473·1	Irons = 18·5
„	N. Bessemer „	92·3	350·7	
„	Y. Siemens „ .	111·6	424·0	
„	B.B. Staffordshire iron	81·6	310·1	
„	D.D. Yorkshire „	103·1	391·7	

The tensile test of the irons and steels supplied by the firms from whom these plates were obtained are given in the Appendix, Table 2. Though the pieces tested were not from the same plates as some of those tried in the boilers, the results, coupled with those since supplied, furnish a fair idea of the softness or ductility of those metals, and may bear some relation to the losses sustained by them.

Turning again to the results of the tube experiments given in Tables I., II. and III., it will be observed that the four Fs ordinary tubes only lost 311·19 grains per square foot of surface, whilst the twelve, consisting of Aɪ, D and E tubes, specially prepared, lost 691·68 grains, the difference being 122·2 per cent. in favour of the former. Again, whilst the four A ɪ tubes named "Improved metal" lost 596·53 grains per square foot of surface, the E tubes called "Improved Homogeneous Metal," by far the more ductile and expensive of the two, and made by the same firm, lost 782·07 grains per square foot of surface; the difference in favour of the coarser metal being 31·1 per cent., the conditions of working being the same. On looking at the results of the cold-bending test of the "Improved Metal"—the coarser of the two last-named—it appears that while two of the pieces were doubled and hammered together flat without showing any signs of distress, the third began to give way when bent to 26° only. So great was the difference that it was hard to believe that the tubes were manufactured by the same firm and of one brand.

Recent analyses of some of the brands of metal under consideration confirm the conclusions the Author has drawn from the results of these experiments, viz., that the commoner sorts of iron, containing the most phosphorus, resist corrosion far better than the superior kinds; and also that the harder steels, containing the greatest amount of carbon and phosphorus, are better in this respect than the softer and finer sorts.

In the cruder classes of iron the percentage of phosphorus appears to range from 0·20 to 0·21, while in the better sorts it ranges from 0·07 to 0·14. In the milder steels it varies from 0·016 to 0·04 only. The percentage of carbon appears to be much about the same in all irons, varying only from 0·0545 to 0·074, while in the mild steels it ranges from 0·131 to 0·273. From 0·0649 to 0·1080 per cent. of manganese is found in the irons, and from 0·238 to as much as 0·75 per cent. in the steels.

Taking three brands of iron and three of steel, it appears that while the total amount of carbon in 3 tons of the irons, 1 ton of each brand, amounts to only 4 lbs. 1½ oz., in a similar quantity of the steels it amounts to 14 lbs.; and that while 3 tons of the irons contain 10 lbs. 1½ oz. of phosphorus, the same quantity of the steels contains only 2 lbs. 0¾ oz.

It would seem, therefore, that much yet remains to be done, both by the manufacturer and the chemist, in order to produce a metal possessing strength and ductility, but at the same time much better able than the present mild steel to resist corrosion. On the other hand, the treatment of boilers might be so modified, especially with the aid of zinc properly applied, that the purer metals might be used for their construction without suffering the severe corrosion to which they are now liable.

With regard to the experiments quoted in this Paper, it may be said that more definite results would have been obtained from more extensive trials; but to this it may be replied, that all experiments in which the conditions are not precisely similar cannot be considered satisfactory. Even when a steel boiler is worked side by side with an iron boiler, and is treated as nearly as possible in the same manner, causes arise, and will arise, to make the conditions somewhat different and the results unsatisfactory. And again, there is the difficulty in such matters of obtaining reliable evidence from mere observations, however carefully and honestly they may be made. Therefore it is contended that for cases such as have here been dealt with, and especially for short periods, the weighing scale is by far the most truthful means of ascertaining results.

The Author has made a point in this Paper of giving facts, and not indulging in assumptions and theories; in discussions on this important subject, there has hitherto been too great a tendency to follow up fanciful opinions, and to disregard ascertained facts.

Before concluding, mention may be made of the composite boilers constructed by the Admiralty in accordance with the recommendations of the late Boiler Committee. The shells of these boilers are of alternate rings of iron and steel, and in each there is a steel and an iron furnace. In one boiler the front end and the front tube-plate are of iron, and the back tube-plate of steel; in the other boiler the reverse is the case. Two sets of two each were made, but unfortunately much delay ensued before they were sent to sea. It will be admitted, setting aside the galvanic action theory, that this is a thoroughly practical experiment, and well worthy of careful attention. Perhaps it would have been still better if the iron shell-plates had been of a brand in ordinary use, and not of the best Yorkshire iron. The furnaces and combustion chambers would have been quite sufficient to test the latter metal against steel. Two of these boilers have now been about three years in commission, and it would be interesting to know their present condition.

For the courtesy always shown by the Engineer-in-Chief of Her Majesty's Navy, and the assistance rendered by the Secretary to the Boiler Committee to the Author in the preparation of this Paper, especially with regard to the ocean-plate experiments, he takes this opportunity of tendering his best thanks.

The Paper is accompanied by several diagrams, from which the woodcuts have been prepared.

[APPENDIX.

APPENDIX.

TABLE 1.—TENSILE STRENGTH of TUBES.

After Annealing.

Tube.	Angle at which it began to Fracture.	Angle at which it Fractured through or otherwise.	Appearance of Fracture, &c.
A.I. 1	105°, slightly distressed.	$\frac{5}{16}$ semicircle, at crown; gone half through.	Crystalline, and rather fine in grain.
B.W. 3	107°, slightly at centre; edges perfect.	$\frac{7}{16}$ semicircle, $\frac{1}{16}$ open at centre; edges gone half through.	Steely, but coarser in grain than the tempered pieces of same metal.
B.F. 2	..	Bent over and flattened at crown, and only very slightly distressed.	
C. 2	..	Much the same in every respect as the former.	
D. 1	..	Bent over and flattened, scarcely at all distressed.	
E. 1	90°, slightly distressed. 152°, one edge half through.	$\frac{1}{8}$ semicircle through.	Fibrous; total absence of crystals.
F.F. 3	..	Bent over and flattened, without any distress.	
F.S. 4	90°, one edge slightly.	160°, both sides through.	Fibrous, with slight crystals.
G. 3	$\frac{1}{8}$ semicircle, one side through.	Flattened; one side perfect.	Fine, and slightly steely only.
H. 3	$\frac{5}{16}$ semicircle, half through.	$\frac{3}{16}$, through.	Fine and slightly steely.
A.Y.	90°, slightly.	180°, through.	Fibrous, and slightly crystalline only.

TABLE 1 (*continued*).

After Tempering.

Tube.	Angle at which it began to Fracture.	Angle at which it Fractured through or otherwise.	Appearance of Fracture, &c.
A.I. 1	90° slightly distressed.	⅛ semicircle at crown, through in two places.	Crystalline and fine; but slightly fibrous at the extended side (crown).
B.W. 1	..	8° without warning . . .	Exceedingly fine and steely; similar to the finest tool steel.
,, 3	..	4° suddenly, without warning	If anything, this is finer than 1.
,, 4	11° nearly through, held together at one corner.	11° separated by hand . .	Much the same as 2.
,, 5	..	0° suddenly, without bending	Very fine and steely; if anything, more so than 3.
,, 2	6° nearly through, suddenly.	22° through	Very much the same as 1.
B.F. 1	35° slightly, at one edge only.	52° ,, ...	At one edge fine and steely, similar to B.W. 1; but towards the other edge a little coarser.
,, 2	..	11° ,, ...	Very fine and steely; much the same as finest edge of 1.
,, 3_1	34° slightly, at both edges.	44° ,, ...	Nearly as coarse as A.I. 1, and quite different to the former ones.
,, 3	18° slightly. . .	22° ,, ...	Much finer than former piece, but not equal to B.F. 1.
,, 5	..	5° through, in two places suddenly.	Coarse and hard; but a little finer in grain than 3_1.
C. 1	74° slightly. . .	90° through	Slightly coarser than coarsest edge of B.F. 1, but less affected by hardening.
,, 2	72° nearly through.	87° ,, ...	Slightly coarser than B.F. 2, and showing want of uniformity (slightly).
,, 3	36° one side, half through only; the other slightly.	50° ,, ...	Much the same as 2, but more uniform.
D. 1	..	Much the same as the annealed strip.	Not affected by hardening in the slightest degree; very soft.
E. 2	26° at one edge only; 58° ¾ across.	70° through, one edge holding nearly to the last.	Crystalline, and much coarser than A.I. 1; more like ordinary iron.
,, 4	..	Bent and hammered flat without any signs of fracture.	Strong, but ductile; and quite different to 2 (the former).
,, 6	..	,, ,, ,,	In all respects the same as 4.
F.F. 3	11° at one edge, slightly.	44° through, suddenly . .	Fine and steely, but a little coarser than C. 3, and not quite uniform.
,, 4	..	0° suddenly, without bending	A little finer than 3, and uniform.
,, 5	9° one edge, through; 49° the other, slightly.	79° the other edge, through	Fine and steely at one edge (¼), the rest much coarser.
,, 6	12° one edge, slightly; 28° the other.	57° through	Much the same as 3. All the F.F. show a want of uniformity.
F.A. 1	1/12 semicircle, slightly	¼ through, half way across, the other perfect when flattened.	Fibrous, and much better than 4.
G. 1	40° slightly, at one edge only.	145°, the other edge half through.	Fine and silky; less affected by hardening than any of the steels.
,, 3	..	0° through, suddenly . .	Very fine and steely; laminated at one edge.
,, 4	..	0° ,, ,, . .	Coarser than 3 in grain.
,, 5	16° slightly, at one edge.	90° ,, both edges . .	Edges fine and steely; centre dirty and laminated.
H. 1	..	0° ,, without bending	Fine in grain; steely and hard.
,, 3	..	0° ,, ,, ,,	Much the same in every respect as 1.
A.Y.	..	..	Much the same in every respect as the annealed piece; not affected by hardening.

TABLE 2.—TENSILE STRENGTH

Test strip.					With or Across the Grain.	Breaking Weight per Square Inch of Original Section.	Area of Fracture.
Letter marked with,	Metal.	Original Section.		Area.			
		Width.	Thickness.				
		Inch.	Inch.	Sq. Inch.		Tons.	Sq. Inch.
J.[1]	Firth's crucible steel . . .	1·510	0·424	0·64024	With.	34·2645	0·52820
"		1·510	0·424	0·64024	Across	31·1406	0·37514
"	Firth's special steel . . .	1·510	0·310	0·46810	With.	34·1807	0·38445
"		1·510	0·310	0·46810	Across.	32·9790	0·32110
J.	" "	1·500	0·510	0·76500	Not ascertained.	30·7180	0·37100
J.	" "	1·500	0·510	0·76500		30·7180	0·37100
N.[1]	Bolton Bessemer steel . . .	1·510	0·370	0·55870	With.	33·2244	0·25506
"		1·510	0·370	0·55870	Across.	33·8956	0·27283
N.	Bolton steel .	1·500	0·485	0·72700	Not ascertained.	30·9490	0·37900
"	" "	1·500	0·485	0·72700		31·2920	0·32200
"	" "	1·510	0·500	0·75500		26·3240	0·34900
"	" "	1·510	0·500	0·75500		26·3240	0·32600
Y.[1]	Landore Siemens steel . . .	1·500	0·437	0·70900	With.	25·3878	0·30800
"		1·500	0·437	0·70900	Across.	25·2997	0·33700
Y.	Landore steel .	1·500	0·500	0·75000	Not ascertained.	26·3330	0·36000
"	" "	1·500	0·500	0·75000		26·3330	0·31800
"	" "	1·500	0·510	0·76500		28·9210	0·41300
"	" "	1·500	0·510	0·76500		29·7380	0·54400
"	" "	1·500	0·510	0·76500		28·4310	0·40600
"	" "	1·500	0·510	0·76500		28·4310	0·40700
"	" "	1·500	0·490	0·73500		28·5710	0·39200
"	" "	1·500	0·490	0·73500		28·5710	0·38000
"	" "	1·500	0·505	0·75700		28·5660	0·41100
"	" "	1·500	0·505	0·75700		28·5660	0·36600
B. B.[1]	Staffordshire iron, Brown & Co. . . .	1·510	0·368	0·55641	With.	20·5556	0·47058
"		1·510	0·368	0·55641	Across.	20·8926	0·51474
B. B.	Staffordshire iron (name not given) .	1·500	0·495	0·74200	Not ascertained.	23·9210	0·51300
"		1·500	0·490	0·73500		22·9590	0·63600
D. D.	Lowmoor iron .	1·500	0·520	0·78000		21·0730	0·66400
"	" "	1·500	0·510	0·76500		20·8330	0·65000
"	" "	1·500	0·520	0·78000		20·1920	0·68200
"	" "	1·500	0·520	0·78000		22·4350	0·64800
"	" "	1·500	0·520	0·78000		21·9550	0·67700
"	" "	1·505	0·525	0·78700		22·5540	0·62000
D. D.[1]	" "	1·515	0·404	0·61084	With.	20·9749	0·49836
"	" "	1·515	0·404	0·61084	Across.	18·9286	0·51178

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[1] Tested in 1876 at Sheerness Dockyard. Those without (1) in December 1879 at Chatham Dockyard.

of the METALS TESTED in BOILERS, &c.

Reduction of Area per Cent.	Breaking Weight per Square Inch of Fractured Section.	Elongation.		Strain at which it began to Elongate.	Remarks On Appearance of Fracture, &c.
		In a Length of 4 Inches.	Per Cent.		
	Tons.	Inch.		Tons.	
17·5	41·5401	0·547	13·675	13·8619	Steely, fine in grain and homogeneous.
41·4	53·1462	0·934	23·575	12·8857	
17·9	41·6178	0·513	12·825	16·6898	Steely, but one edge much coarser than the other.
31·4	48·0769	0·627	15·675	13·3518	
51·5	63·3420	1·250	31·250	Not ascertained.	Fine, grey and silky. Fair break.
51·5	63·3420	1·060	26·500		
54·3	72·7769	1·110	27·750	16·4444	Grey, grain fine and silky.
51·2	69·4160	0·978	24·450	19·1292	
47·8	59·3660	1·060	26·500	Not ascertained.	Sound, slightly fibrous. Fair break.
55·7	70·6520	1·060	26·500		Fine, grey and silky. Fair break.
53·8	56·9480	1·180	29·500		Grey, grain fine and silky. ,,
56·8	60·9660	1·310	32·750		Very slightly laminated, but fibrous. Fair break.
56·5	58·4781	1·170	29·250	15·5148	Fine, silky grey and homogeneous.
52·5	53·2270	1·046	26·150	15·5148	
52·0	54·861	1·310	32·750		Sound and fibrous. Fair break.
57·6	62·106	1·370	34·250	Not ascertained.	,, fine, grey and silky. ,,
46·0	53·571	1·060	26·500		Laminated, dull grey and fibrous. Fair break.
28·9	41·819	1·000	25·000		Laminated slightly, grey and silky. Fair break.
47·0	53·571	1·1200	28·000		Slightly dirty at centre and fibrous. Fair break.
46·9	53·439	1·0600	26·500		Slightly laminated and fibrous. Fair break.
46·7	53·571	1·0600	26·500		Sound and fibrous. Fair break.
54·0	64·349	1·1800	29·500		,, grey and silky. ,,
45·7	52·615	1·1800	29·500		Very slightly unsound at centre and silky. Fair break.
51·6	59·084	1·1200	28·000		Slightly laminated and silky. Fair break.
15·4	24·2099	0·4700	11·750	7·0765	Dark grey and fibrous spots of crystals in places, and slightly laminated.
7·5	22·5842	0·1780	4·450	14·6202	Much the same, but more laminated.
30·8	34·6000	1·0000	25·000	Not ascertained.	Laminated and dirty. Fair break.
13·5	26·5330	0·3700	9·250		One-third crystalline and laminated. Fair break.
14·9	24·7550	0·5600	14·000		Sound, grey and fibrous. Broke at shoulder.
15·0	24·5190	0·5000	12·500		Sound and fibrous. Broke in middle.
12·6	23·0930	0·3700	9·250		Soft and fibrous, but laminated. Broke at shoulder.
16·9	27·0060	0·4300	10·750		Fibrous, badly laminated. Fair break.
13·2	25·2950	0·5600	14·000		Fibrous, but dull and slightly laminated. Broke at shoulder.
21·2	28·6290	0·6200	15·500		Fibrous and slightly laminated. Fair break.
18·4	25·7089	0·5310	13·275	10·9478	Dark grey and fibrous.
16·0	22·5925	0·4000	10·000	9·7200	,, ,,

Discussion.

Dr. Siemens.

Dr. C. W. SIEMENS said, it perhaps would have been better if the discussion had been commenced by persons more interested in the use of iron and steel, than by those who, like himself, were intimately connected with their production; but in another respect it might possibly save the time of the Institution, if he took that early opportunity of referring to some conclusions in the Paper with which he could not agree. The Author had given the results of elaborate experiments on a subject which was of the utmost importance to engineers; and if his conclusions were to be relied upon, engineers were daily committing a grave error in using a material which gave so slight a guarantee of endurance. But while he accepted every one of the experimental facts adduced by the Author, he thought he was in a position to prove, from the Author's figures alone, that his conclusions were entirely erroneous. He had referred, in the first place, to a long series of experiments made by the Admiralty, under the direction of Admiral Aynsley, and as far as the collection of facts was concerned, nothing could be more conscientious or thorough than that series of experiments; but as regards proof, they went no further than to show what every experimenter ought to avoid, and how he ought not to conduct his experiments in the future. The Author had placed before the Institution the apparatus then used. It consisted of thirty-eight tubes of iron and steel riveted in metallic contact with the shell of a boiler, and exposed partly to air and partly to hot water and solutions. Although the Author had a very poor opinion of electricity and its effects, Dr. Siemens had a strong belief in electricity wherever it had a chance of acting for good or for evil, and he was convinced that the results obtained in those experiments were rendered entirely unreliable owing to galvanic agency. The results were most variable. Whereas one iron (common iron seemed to be the best) gave a corrosion of only 7 grains, on an average, per square foot, Bessemer steel gave 21 grains, or three times the amount during the time of exposure. The Author was really most merciful when he stated that the result was only 69·3 per cent. in favour of iron, because it was really 300 per cent. in that instance. Notwithstanding these experiments, the Admiralty had adopted a mode of action which seemed strangely at variance with the conclusions to which the experiments would point. They now used steel al
to the exclusion of iron, and he hoped that s

Dr. Siemen

with the Admiralty would state the result of more recent experiments undertaken with a better knowledge of the conditions under which they should be made. He believed the conclusions since arrived at were very different from those deduced by Admiral Aynsley some years ago. At Table VII. the Author had compared Landore metal and iron, the one giving an average loss per square foot of 506·24 grains, and the other of 483·17 grains, showing a difference of only 4·8 per cent. against the steel, and that was, at any rate, a great deal better than 69 per cent. On the same page, the Author stated, "The only peculiarity worth noticing in this experiment is that, while the two plates in the feed-water heater lost 381·8 and 394·2 grains, the two in the boiler fed from the heater lost only 8·0 and 3·4 grains respectively." Therefore in the boiler the iron lost by corrosion about one forty-eighth, and the steel about one hundred and twentieth of what they respectively lost in the feed-water heater, the loss of iron in this case being about two and a half times that of the steel. In Table IX., set 98, the Y steel produced by the Siemens process gave a corrosion of 1,220 grains, and the DD. Yorkshire iron 1,221 grains, in each case per square foot of surface; the corrosion in those instances being practically the same. In the next set, 99, the Y steel gave a corrosion of 259 grains; Staffordshire iron 269 grains, and DD. Yorkshire iron 260 grains; showing that the steel came out best in that series. In set 102, the Y steel gave 109·5 grains (in rain water), and the DD. Yorkshire iron 144 grains. And yet the Author followed up these facts with the conclusion that steel corroded on an average 64·8 per cent. more rapidly than iron. He entirely objected to the mode of reasoning adopted; he contended that averages were only applicable to errors of observation. If an observer was not certain of his weighings, and he made a hundred weighings of the same piece of iron, he would be perfectly justified in taking the average. But nothing could be more unscientific or erroneous than averaging several materials, one group of which he chose to call iron, and another which he called steel. It was as if a moral philosopher wanted to find out whether fair complexioned people were more virtuous than dark complexioned people, and were to take six fair people and six dark people promiscuously; then finding that they were all very well behaved,. except one of the fair people, who happened to have just escaped from gaol, and had committed six [illegible], he were to draw his average and say, "I find that fair [illegible] have [illegible] an average, one murder each, and [illegible]sted." That was the kind of argu-

h. Siemens. ment which the Author appeared to have adopted. There were substances, compounds of iron, manganese, and silicon, sold for steel, which no doubt corroded very rapidly; but it was for the consumer not only to select the proper material, but also to see that it was properly used. He believed it was in regard to the proper selection and use of the materials that the enormous discrepancies with which they had to deal would be found. The Author stated that there was more cinder in iron than in steel, and therefore that there was *primâ facie* ground for supposing that iron would corrode more than steel. There was, however, an essential difference between cinder in iron and the scale of steel. The cinder in iron was a glassy substance, which was a dielectric, and therefore had no effect upon the corrosion of the metal, whereas the scale on steel, which was produced in rolling, had a very deteriorating influence; it was a magnetic oxide, which was negative to the steel, and wherever the metal was exposed in the presence of such magnetic oxide, corrosion took place rapidly. Again, if the scale should be rolled into steel plates, as was sometimes the case, rapid corrosion ensued, for the same reason. But he need hardly say that with proper care those causes of undue corrosion could be and were prevented, and the extensive use to which steel was now put proved sufficiently that there was, at any rate in ordinary practice, no such destructive effect going on. The Author stated that those interested in steel had been singularly negligent in not following up the question of corrosion. Being himself much interested in steel, Dr. Siemens had for some years caused a running set of experiments to be carried out by Mr. Willis, the chemist at Landore, which told a very different story from the Author's. In one series, extending over six months, made partly in a boiler supplied with salt water, and partly by exposure in a tidal river—the plates being exposed to the air for six hours, and then immersed for six hours in salt water—the result was in some instances of open exposure slightly in favour of iron, but, in the cases of boilers, always very much in favour of steel. He had just received a report from Mr. Willis, in which reference was made to a point of importance, the perfect cleaning of the surfaces. It had been found that if the surfaces were carefully cleaned of oxide by dipping the plates in the first instance in an acid solution, the corrosion was always much diminished. The evil effects of scale on steel were pointed out at the Institution of Naval Architects,[1] by Mr.

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[1] *Vide* Transactions of the Institution of Naval Architects, vol. xx., p. 225.

Dr. Siemens. Barnaby, on the 5th of April, 1879, when he clearly showed that the magnetic oxide scale was very deleterious in its effects. He believed that it was now the practice of the Admiralty to clean the scale off before using the plates for shipbuilding. During the past week he had received a number of letters, quite unsolicited, from gentlemen interested in the use of steel, all speaking in the most definite manner in favour of steel as a metal not liable to corrode under ordinary circumstances. One of them was from the Clyde Bank Foundry, in which it was stated by Mr. Thompson that forty steel boilers had been at work for more than two years, and that their examinations had led to the conclusion that no active corrosion was going on. He believed it would be found, from general experience, that steel under proper conditions lasted at least as well as iron. He hoped that the discussion would bring out such further facts as would put the question practically at rest. That there was, under certain conditions, a very active corrosion going on both upon steel and iron was clearly proved by the Paper, and by other experiments; but the conclusions drawn by the Author in favour of iron were, he thought, unjustified by the results of his own experiments as well as of others.

Mr. Traill. Mr. **Thomas W. Traill** considered that the Paper showed evident signs of great labour having been bestowed upon it; but, without wishing in any way to detract from its merits, he thought that had the facts been derived from the actual employment of steel in the construction of marine boilers they would have been more useful and perhaps as interesting. Steel was used in the construction of ships and boilers about a quarter of a century ago, but it did not then, in his opinion, receive a fair trial. That also was the opinion of many others; and owing to a few failures the users of steel became frightened, and did not take the trouble to find out the cause of the failures, and it had not a fair chance given to it to run a successful race with iron. It often got spoiled in the manipulation, and after it was placed in the structure it did not receive the kindly treatment due to a new material, if it was to have a chance of existence. The result was that it had been neglected for years. Twenty-two years ago, to his knowledge, a pair of boilers made of steel were placed in a vessel, and they did not suffer corrosion more than if they had been made of iron; in fact, they corroded less than any boilers he had ever seen, though they were used under the most trying circumstances. They did not for about five years receive any repairs except from the engine-room staff. Many

Mr. Traill. ships had been constructed of steel, and from all he could learn from trustworthy sources, and also from personal observation, those ships, after many years' working, had shown nothing to distress or alarm any one as far as corrosion was concerned. Mild steel, as it was called, had been much used in marine boilers during the last few years, and he had certainly not seen or heard anything that would justify him in expressing an adverse opinion respecting its use in regard to corrosion. Only on the preceding day he had received a letter from a friend who had made many steel boilers and placed them in ships, and he stated: "We are carefully watching the steel boilers made by us in ships running to this port, and so far everything is satisfactory; there is no corrosion, and they keep very tight." He believed that those boilers were about two years old. He hoped that, if any note of alarm was raised on the subject, it would be founded on established facts derived from the actual use of steel in marine boilers. He had certainly heard nothing to justify the opinion that steel was not fit to run a successful race with iron, so far as its corrosive properties were concerned.

Mr. Martell. Mr. B. MARTELL thought engineers were much indebted to the Author for bringing his valuable experiments before them. When it was remembered that at the present time 82,000 tons of steel ships were being built, the great importance of the subject would be at once recognised. The question of the mechanical properties of mild steel was no doubt well understood. It was known that it could be produced possessing all the qualities required for ship purposes (he referred especially to the hulls of ships), with all the ductility and strength, as compared with iron, that could be hoped for in a material of that kind. The question of corrosion, however, was one that required to be solved, and for that purpose more information was needed than had been hitherto obtained. Many shipowners were anxious to build ships of steel, but an opinion was abroad that it deteriorated more quickly than iron; hence the importance of having reliable facts upon which to form a correct opinion on that branch of the subject. About eighteen months ago a steel ship, not a year old, was hauled up on a slip-way in the North of England; he went there for the purpose of examining her, and his examination appeared to bear out in a striking manner one of the results mentioned by the Author, who had shown the rapid deterioration that took place where steel was exposed alternately to salt water and to air. The vessel was riveted with iron rivets, and he found that between the

Mr. Marte

light water mark and the load water mark, which was alternately wet with sea-water and then dry and exposed to the air, a rapid deterioration had taken place as compared with the other parts of the vessel, and with iron vessels; in fact the steel round the rivets had wasted to a considerable extent, so that the rivet points were protruding some distance beyond the steel. He thought it might probably be due to galvanic action. Dr. Siemens had referred to magnetic oxide, but that could not have been the explanation, because by hammering the rivets the whole of that would have been certainly beaten off. He attributed it more to the galvanic action taking place to some extent between the iron rivets and the steel plates. The result seemed to show that under such conditions as those to which he had referred a more rapid deterioration ensued than under other circumstances. Two months ago, however, that same vessel, which had been continuously running since, was hauled up again and thoroughly examined, and owing to the greater care taken in protecting that part, no deterioration of any moment had taken place more than in any other part of the vessel. A striking and important fact was at the same time brought out. The vessel was constructed with a double bottom, or water ballast tank, extending fore and aft, and inside that no deterioration had taken place beyond what would have occurred in iron, and possibly less. That seemed to show, that where steel was entirely immersed in water no more rapid deterioration followed than in iron. He was of opinion that the results stated by the Author might be correct, but they would not prevent his adopting steel for ships in preference to iron. Mild steel was superior to iron for every purpose for which it was used mechanically, and by continually coating the surfaces it could be protected as much as iron. With regard to chemical action, he had known an iron vessel carrying sugar, in which some of the bottom plates had been eaten through in a few months, and nothing could be worse than that with the use of steel. But there, again, there existed an excellent preservative in Portland cement, which would protect the bottom from any action of that kind. The inside was open to observation, and it could always be coated. By the use of steel the ship was stronger, and most of the parts could be protected from deterioration, with the exception of that between the light and the load line, and that only required a little closer attention in keeping it coated so as to prevent rapid corrosion. He hoped the result of the Paper and of the discussion would not be to scare shipowners from the use of steel. He trusted it would

Mr. Martell. not be considered, as the result of experience, that steel had deteriorated 120 per cent. more than iron, as would appear to be the case from some of these experiments; but that the facts derived from the actual wear and tear of ships would be considered before any decisive conclusion was arrived at.

Mr. Barnaby. Mr. N. BARNABY, C.B., drew attention to the statement in the Paper that (p. 87): "In spite of these reasonings, it is undoubtedly a fact, that under almost all circumstances iron, and particularly the harder classes, is far superior to the finer steels in its resistance to corrosion, and this the experiments described by the Author incontestably prove." When he saw that paragraph he remarked to the engineer-in-chief of the Admiralty, Mr. Wright, who was a member of the first Boiler Committee (of which the Author was also a member), and had continued the experiments to the present time, "It is necessary that there should be some explanation with regard to this, because we are using steel shells for boilers very largely, and people will expect that some one from the Admiralty should say whether this statement, derived from Admiralty experiments, has been borne out by later work." Mr. Wright replied, "We have continued the experiments from the time when Mr. Phillips left the Boiler Committee, and we have come to the conclusion that there is no difference in the rate of corrosion between iron and the mild steels we are using. By such experiments as those which he conducted, and which have been continued since, so far as we can make out, the results are pretty nearly the same." He stated, moreover, that steels could be as well protected as iron by zinc suspended in boilers. That was the justification for the present practice of the Admiralty in using mild steel for the shells of boilers. That practice was a very recent one, the Admiralty having commenced making steel boilers only within the last few years; and it was hardly right that he should speak of it when there were so many others who had had a long experience of the use of steel in boilers. His only justification in alluding to the subject was that engineers might wonder how it happened that the Admiralty report, as the Author had presented it, should not be in accordance with the present Admiralty practice. With regard to what Dr. Siemens had said as to the effect of the hard black oxide upon the surface of steel, it was true they discovered a long time ago that the effect of that oxide was very strong indeed, almost like that of copper, yet they were foolish enough (he could use no other word), in building two ships at Pembroke, to allow them to be coated with anti-fouling compo-

Mr. Barna

sition before the black oxide was completely removed. His excuse was that the portions of black oxide remaining were very small, and that the officers who were charged with the duty of getting the bottoms quite clean thought they had done so. It was not until the "Iris" had been at sea for some months that it was discovered that rust was forming under the coat of paint with which the bottom had been covered. The Admiralty had learned wisdom by that occurrence, and he believed it would not happen any more. They now took pains to clear the oxide off completely. He thought the reason why they had found it out before others had discovered it was, that it was the practice in private trade to build vessels of that kind in the open air, and it was there easier for the black oxide to get removed from the surface of the steel. The Admiralty built their ships under cover, where it did not come off so easily.

Mr. Farqu
son.

Mr. J. FARQUHARSON said he had a memorandum showing the importance of removing the oxide. The Admiralty were aware of the view set forth in the Paper, that mild steel was much more liable to corrosion in salt water than iron, long before the Report of the Boiler Committee was printed, and they determined to test that point specifically. The diagram shown scarcely represented the condition in which the experiments mentioned in the Paper were really made. The diagram he now produced he believed showed the actual arrangement that existed. In looking at the diagrams he was of opinion that no reliable inference could be drawn from combinations so complicated and affected by so many conditions. By Mr. Barnaby's directions it was arranged that they should try,—not surfaces partly covered with oxide and partly uncovered, in an apparatus the condition of which they knew nothing about and which was itself made of a different metal,—but plates of iron and steel of a considerable size carefully prepared, the oxide being entirely removed by two processes, first pickling it off by chemical means, and secondly, planing it off to see how far the process of removing it affected the result. The plates formerly had been tried under conditions which had led to the inference that iron corroded a great deal more rapidly than steel; but the result of the experiment when the plates had been divested of oxide on the surface was that they were practically alike; if there was any difference it pointed in favour of iron. It was a rather extended series of experiments carried on at Portsmouth with great care. It was then determined to ascertain something about the electric effect of the oxide, and another series of plates was prepared, each 2 feet long, 1 foot wide, and $\frac{3}{16}$ inch

Farquhar. thick, of mild steel. Some of the plates were prepared in the way he had described—the oxide being removed by two processes. The detached plate from which the oxide had been pickled lost 4 oz. and 70 grains; the one from which it had been removed by planing lost 3 oz. and 390 grains. That was the case with two pieces of the same plate. In another experiment, one plate with the oxide removed as he had described was combined with another plate of the same size, 2 feet long and 1 foot wide, which had been cut from the same piece of Landore steel; they were placed parallel to each other, 3 inches apart, in a wooden frame, and were connected by wire, one with the oxide on, the parts where the oxide was not on being touched over with a protective varnish to prevent local action. The plate with the oxide on lost nothing; the plate in contact with it, combined electrically, lost 10 oz. 95 grains. He had before him the record of another series treated in the same way, but he would only refer to a few instances to show that there was a great amount of harmony in the results. A plate with the oxide pickled in contact with another with the oxide on, held parallel to each other 3 inches apart, immersed in the same way in Portsmouth Harbour, lost 12 oz. and 34 grains; that with the oxide on lost 75 grains—that happening from minute parts unobserved and unprotected by the varnish pitting. With another pair of plates, one with the oxide removed, combined with a copper plate of the same size and placed in precisely the same relation to it as had been the plate with the oxide on, lost 11 oz. 345 grains—which was less than the other plate where steel alone was used, showing that a tolerably compact coating of oxide was as detrimental to steel exposed with the oxide on as copper. There were a number of other experiments, the general result of which was the same. He was considerably surprised when he read Mr. Phillips' Paper. He knew that the experiments of the Boiler Committee had been continued, and he could only suppose that he was not aware of what had happened. Mr. Barnaby had rather understated the case in favour of steel. In most of the cases that had been tested by the second Boiler Committee the results were strongly in favour of steel. Having a full knowledge of the experiments conducted for the Admiralty for some years, his opinion was greatly at variance with that of the Author as to the general result of the comparison between iron and steel. No one acquainted with the electrical effects of the combination of metals would expect to find any reliable inference from such combinations as had been presented. Copper, gun-metal, zinc, iron, steel, had all been combined electrically, and at various distances, some in contact, some supported on metal rods, some on iron, some on steel; and it was stated that the results were so much per cent. in favour of iron. For himself he would not undertake to say what the relative amount of corrosion of iron and steel was with any such combination. Mr. Farquh son.

Mr. JOHN DONALDSON could corroborate the remarks of Dr. Siemens and Mr. Barnaby, as to the evil influence of the presence of black oxide on steel plates, by mentioning two cases which had come under his notice. The practice of his firm, at the time when the boats were built, was to preserve, as far as possible, the oxide on the plates, with a view to prevent them from getting rusted, the oxide itself protecting the plate covered by it from rust. The first case was that of a boat built for service on the west coast of Ireland. For some time after leaving the yard they had most favourable accounts of her performance, but suddenly they received a letter, stating that she had one day gone out fishing, and it was as much as two men could do to keep her from sinking. The boat was examined, and it was found that the plates in the bow and in the stern, and others in the boiler and engine-room, were pitted with very small holes. It appeared as if some of the black oxide had been knocked off in the process of working the plates, and that the oxide left on had contributed to increase the rusting of those parts. At first he thought it was due to the engineer not clearing away the ashes from the stokehole and the soot from under the smoke-box; but an examination of the second case, that of a boat built for the Zoological Station at Naples, seemed to show that it was more the action of the black oxide, helped largely, perhaps, by the plates not being kept well painted. In that case the principal pitting took place at the bow and stern, and scarcely any in the neighbourhood of the engine-room. He therefore concluded that it was the black oxide that had been acting galvanically in oxidizing those parts of the plates that were exposed. When the plates of a boat were well painted and kept clean, very little of that action took place, as was shown in the case of the "Lightning," which his firm built some years ago, and the bottom of which they had lately scraped and painted, the plates being found in excellent condition, due no doubt to the great care taken of the vessel while in the hands of the Admiralty. Their practice now was not only to remove the scale from the plates, but to galvanise the whole of the hulls, and since that had been done there had been no trouble as far as oxidation was concerned. Mr. Donald

r. Phillips.

Mr. D. PHILLIPS said it would appear from the remarks of Dr. Siemens and Mr. Farquharson that the conditions to which the tubes were subjected were not clearly understood. He wished to point out that the tubes were screwed through the tube-plate, which formed the top of the apparatus, and that the tube-plate was covered with a non-conducting material (putty) 2 inches thick, so that the water in the condensing chamber had no admittance to it, and therefore the conditions necessary to promote galvanic action between it and the tubes, or between the tubes themselves, were not present. The lower ends of the tubes were exposed to steam only; for 4 inches above the non-conducting material they were exposed to the circulating water (fresh), and the rest to the vapours arising from the heat of the tubes and tube-plate. The level of the water in the tubes, and in the condensing chamber, and the non-conducting material on the tube plate were shown in Fig. 1.

Sir Henry Bessemer.

Sir HENRY BESSEMER was sure no one could help feeling that the question brought forward in the Paper seriously affected a great deal that had been done within the last twenty years, and was well worthy of investigation. As a preliminary to his remarks he desired to say that he accepted unreservedly all the figures which had been given by the Author; he accepted his experiments as stated, and had no doubt of their entire fairness. But if he were asked from those experiments to draw the inference that mild steel in the form of a boiler such as was ordinarily used would not endure half the amount of use and resist corrosion as well as common Staffordshire plate, and that phosphorus being present in the commoner irons was the cause of its standing so well as compared with mild steel, he must entirely demur to any such conclusion. In the first place, the experiments on plates suspended inside a steam boiler appeared to him to be under totally different conditions from those to which a steam boiler was exposed when in use. A steam boiler in use had its internal flue exposed to a very high temperature on the inside, and on the outside to the water only, subject more or less to a deposit on its surface, and to a great many strains continuously by the raising and lowering of the temperature, which a suspended and insulated plate in the water did not feel or come in contact with. The external shell of the boiler also was exposed on the inside to the corrosive action of the water, and on the exterior to the corrosive action more or less of the gases of the furnace passing along the flues, and also to the escape of water occasionally from the weeping at the rivets, and so on, sometimes

Sir Henry Bessemer.

cutting large notches, or, if the boiler was well riveted, not affecting it at all. To these violent changes of temperature the suspended plate was not subjected. The deposition of scale upon the surface would not take place on the suspended plate in the same manner as in the case of a boiler. The conditions, therefore, were in reality very different, and that difference would sufficiently account for the fact that boilers in actual use did not corrode at the rapid rates that the suspended plates appeared to have done, from the evidence given in the Paper. Some twenty-three years ago he manufactured a great many boiler-plates for a gentleman who was about to make experiments upon their use, and who desired to know what was the actual working condition of those new steel plates. In one instance 50 tons of plates were made into boilers, and the result, after twenty-two years' use, was very different from that which had been described with regard to the suspended plates, in consequence of the different conditions to which they were subjected. As introductory to the experiments, he might be permitted to refer to the remarks made by Mr. Daniel Adamson, M. Inst. C.E. (than whom there was no more thorough and practical man connected with boiler work), and by Mr. William Richardson. The occasion was the discussion on a Paper which he had read on the 31st July, 1861, in Sheffield before the Institution of Mechanical Engineers, Sir William Armstrong occupying the chair. Some specimens of flanging for locomotive boilers were then exhibited, and after they had been examined by the Chairman, the remarks he had referred to were made in reply to an inquiry whether the plates from the new steel were much used.[1] The plates of some of the boilers were exceedingly thin, and if anything like rapid corrosion took place in those plates, they would soon have become too weak to sustain the pressure of 85 lbs. to which they were subjected, and would have given way. It had occurred to him that it would be well to ascertain the condition of those boilers at the present moment, inasmuch as, if corrosion had gone on at the rate stated in the Paper, in connection with some of the Bessemer steel, the plates would have been entirely destroyed in about eight and a half years, and as the boilers were made twenty-two years ago, it might be supposed that a second or third set would now have taken the place of the original ones. He accordingly sent the following telegram to Mr. Richardson :—"A Paper on corrosion of steel boilers will be discussed to-morrow at Civil Engineers;

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[1] *Vide* Institution of Mechanical Engineers, Proceedings, 1861, p. 149.

Sir Henry Bessemer. are the six boilers of my steel, made twenty-two years ago, still in use?" To which Mr. Richardson replied:—"The six boilers of your steel, made twenty-two years ago, are still in use, and have no appearance of corrosion." That was the best answer he could give to the assumption that Bessemer steel lasted about one-third the time of common Staffordshire plates. Had common Staffordshire plates been used twenty-two years ago he fancied that the boilers would be in a rather queer condition at the present time. Mr. Richardson's practice was to overhaul his boilers annually, and thoroughly investigate them; and as the boilers in question were experimental ones, and put up so long ago, he had no doubt that a strict examination had gone on in connection with them, so that Mr. Richardson would well know whether they were corroded or not. This statement was, he thought, the best evidence that could be given that Bessemer steel, and other mild steels of a similar character, were thoroughly well adapted for the manufacture of steam boilers, and might be relied upon quite as well as Staffordshire iron, notwithstanding the results arrived at by the Author.

r. Ravenhill. Mr. J. R. Ravenhill wished to preface his remarks by saying that many of the members of the Boiler Committee had been personal friends of his own for many years, and one of them, Mr. Trickett, the Chief Engineer of Her Majesty's dockyard at Keyham, for thirty-five years. No one, he believed, would venture to doubt that the Report of the Committee was in full accordance with the facts as they appeared to have been at that time. The Committee commenced its operations in 1874. Their third Report was signed on the 9th of August, 1877, Mr. Trickett having ceased to render the Committee the benefit of his services at the end of March 1875. Mr. Barnaby had stated that their own experience since was entirely at variance with the statement laid before the Institution by the Author. The question was, no doubt, a most important one. Steel had been in use, as Sir Henry Bessemer had said, in land boilers, for twenty-two years; vessels had been running between Dover and Calais for nearly the same period, and one of them, the "Samphire," was subjected to perhaps the most severe strain that it was possible for a vessel to be put to. On the day of the Admiralty trial trip the boat had been across from Dover to Calais, and had made a very rapid passage, and on the return was making a still more rapid one. The average speed was nearly 17 knots an hour. With new machinery he felt anxious that the captain should not run matters too fine in approaching Dover,

Mr. Ravenl

but that plenty of time should be given to reverse the engines, and stop the ship, and having explained this, he was himself down below, but the excitement on deck proved too much, and no order was given to either ease, stop, or turn astern until they had come alongside the Admiralty pier head; to turn astern was found impossible, and almost before the words could be uttered, several feet of the vessel's bow were on the rough rocky shore adjoining the pier. The vessel was soon backed off and taken into harbour, but hardly leaked. She was put on the gridiron the next day; the repairs that were necessary were of an unimportant character, but there was one material point in connection with them. The Admiralty shipwright inspecting officer, having been accustomed to wooden shipbuilding, perhaps felt a little anxious when he came to survey a steel ship, and might have had some doubt about her strength. But on examination he was amply satisfied, the certificate was given, and no further test was asked for. A few months afterwards the vessel was in collision with a ship off Dover, and she actually steamed into Dover harbour with her bows submerged, and the water for a considerable distance over her deck forward. He thought there could hardly be a stronger proof to show what steel would stand in connection with shipbuilding. In a letter from Captain Dent, of Holyhead, dated 22nd March 1881, it was stated that the steel steamers under his charge, which had been running for three years, showed no signs of corrosion. No doubt there was a difference in the quality of the steel used in the Holyhead boats from that used at Dover, but he thought it was fair to argue that if the steel was preserved, when well looked after, for three years, it would probably remain good as long as the steel in the Dover boats. The boats running across the channel had not the space between the load line and the light line, to which Mr. Martell had alluded, but the action on steel closely resembled that used in the series of experiments Table IX., set 100, where a comparison was made between Bessemer steel and Staffordshire iron, and Siemens steel and Yorkshire iron. The Bessemer steel and Staffordshire iron were exposed to the weather, and dipped in sea water daily, and for a few feet up the side of the vessel, above the water line, a very similar action went on. Any one could go to Dover and see what the effect on the vessels had been after so many years' running; but according to the experiments, there ought now to be little of the original steel left, for the comparison was 128 per cent. in favour of iron. The plates in the Dover boats were $\frac{5}{16}$ inch thick, and they were certainly a striking example of the endurance

r. Ravenhill. of steel. The Author had alluded to the boilers of "The Duke of Sutherland," and said it would be interesting to know their condition at the present time. In the letter to which he had alluded, Captain Dent stated, "We find no appreciable difference between our iron and steel boilers, now nearly five years old." He had been informed through another channel that these steel boilers in places showed marks of corrosion more than they did in others. So also would iron ones; and any practical man who had been in the habit of examining marine boilers, would say that on going on board a vessel fitted with eight different iron boilers, and going inside them, in no two cases would the appearances be similar. There had been instances in the cases of stays in the steam space where steel had rapidly corroded, but the same thing might also occur in iron boilers. The quickest corrosion might be expected to take place in the stays just about the water-line, and in the steam space. It would be found that a few perished very rapidly, while others, for no accountable reason, stood perfectly sound and good. There was no doubt a difference in the quality of the material, and it was much to be regretted that the valuable experiments made up to a certain date by the Boiler Committee did not go further and record the difference, if any, from a given standard, in the component parts of the metals subjected to experiment. Unless there were some such standard, makers might be easily scared. He remembered the time when a number of boiler tubes gave way the first time the fires were lighted; they were taken out, and some spare ones were substituted, and again they failed. What was the result? The chemists were set to work, and a standard of metal fixed for the future. From that time to the present the Admiralty work had been subjected to chemical tests, and it was known that if it would stand those tests there would be no further trouble with the boiler tubes. He well remembered the scare in connection with iron boilers. The plates were pitted, and, after four trips up the Mediterranean, were nearly worn away, being so thin that it was thought the boilers were not safe to go to sea. A few repairs were done; the boilers were roomy, and the parts where rapid corrosion had taken place were coated with Portland cement; the boilers then did the usual amount of work. The Committee had alluded to the action of zinc. In a Paper which he had read at the United Service Institution,[1] he stated, with the full sanction of the Admiralty, that their experiments up to that time tended to show, that if the

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[1] *Vide* "Journal of the Royal United Service Institution," vol. xxiii., p. 602.

Mr. Rave

most valuable properties of zinc plates were to be obtained, they should be placed all over the inside of the boiler, at distances of not more than 6 feet apart. In conversation with the Engineer-in-chief of the Admiralty, he had been informed that their experience up to the present year was that, where zinc was properly applied in marine boilers, steel lasted as well as iron; and that they were driven to the use of zinc in iron boilers before they began to fit steel ones on board. The Author had stated, "On the other hand, the treatment of [marine] boilers might be so modified, especially with the aid of zinc properly applied, that the purer metals might be used for their construction." He was surprised, after this lapse of time since the Report of the Boiler Committee appeared, that the Author should have put such a statement before the members. His principal object in drawing attention to the subject was to prevent any prejudice against the use of steel for shipbuilding or boiler-making. With regard to shipbuilding, there were instances of owners who had had ships running for a short period, say two years, repeating their orders for steel. The very company to which the Author of the Paper formerly belonged, the Peninsular and Oriental, had now in course of construction five large vessels of steel; and the rapid increase in the use of steel for boilers was marvellous.

Mr. Matl

Mr. E. MATHESON said the Author had dwelt entirely upon boiler tubes and ships; but there were other matters in connection with the corrosion of steel and iron which were interesting to many members of the Institution; he referred to structures like bridges, exposed not to salt water or steam, but to the weather. The corrosion of wrought iron was very serious, especially in cities and in railway tunnels, and if steel were still more sensitive to corrosion, it would indeed be a grave matter. It would be interesting to compare the means taken to preserve wrought iron with those used in connection with steel, and to see how one would be suited for the other. He thought that the means taken to protect wrought iron from rust were imperfectly understood. There always appeared to be an attempt to preserve the skin of the iron as it left the rolling mill, and he ventured to say that that was impossible, and was to a large extent a mistake. Wrought iron, in passing through the rolls, coming in contact with the atmosphere, was at once oxidised; it got a black scale or oxide upon it which must ultimately fall off; and although elaborate specifications were prepared for oiling or painting such wrought iron, that treatment only postponed the evil. Oiling wrought iron was, he thought, a better protection than painting, but even that did not fulfil the purpose intended. He

r. Matheson. believed there were only two, or perhaps three, modes of protecting wrought iron from rust. One was to keep it entirely from the air. Iron built into lime or brickwork or masonry would remain for centuries almost in the same condition as when it was put in. The second plan was that of Professor Barff, exposing the iron to superheated steam, but this was possible only with pieces of moderate size. A third plan was to remove the thin scale entirely before the painting was applied, and he thought that was seldom, if ever, done in England in any sort of structure. The only place where he knew of its being done was in Holland, where the specifications of the engineers generally described, with the greatest minuteness, how the iron was to be treated before the oil and paint were applied. The iron was treated as the galvanisers treated it in this country; it was dipped in baths of dilute acid, which removed all the black scale. After washing it was painted, and if the paint was renewed from time to time, the iron might be permanently preserved. In this country the plan was followed necessarily by galvanisers, but he believed by no one else. If the structure had parts that were inaccessible to the painter's brush, rust would be sure to destroy it. He had lately seen a curious instance of the way in which rust deteriorated structures. He had taken down a beautifully-made bridge that had been put up twenty-five years ago by Messrs. Fox and Henderson; it was the first pin-connected bridge made in England, and was placed over the Commercial Road at Stepney. The upper boom or box of the bridge had been riveted and caulked like a boiler, and was perfectly air-tight; and the inside plates, which had never been painted, were as good as the day when they were first put in, while some of the parts exposed to the atmosphere, and ineffectually painted, had deep pits bitten out in all directions, materially weakening them. The worst part was where the iron had been brought in contact with wood, the acid of which had so destroyed it that an angle-iron ½ inch thick was worn down to a knife edge. It was not often that one had the opportunity of dissecting an existing bridge, and he thought it might be interesting to mention the facts to which he had referred. Another bridge, an approach to a large terminus, put up some twenty years ago, was now being taken down (having to be widened) in the City of London; the rivet-heads were eaten away, and the T-iron stiffeners were nearly rusted away. At the present rate, in ten years he imagined the bridge would have begun to sink under its load. When he saw it there were four locomotives on it, so that it had to undergo severe strains. It would be interesting if some steel-maker or chemist would

Mr. Math compare steel with cast iron. Like cast iron, it had been in a molten condition, and had not undergone the intermediary process of piling and laminating which wrought iron had to undergo. Cast iron, when run into a sand-mould, got a skin on it, which was a very valuable protection, and might be permanently preserved. Steel was cast in an ingot, and it might be useful to be informed, by those cognizant of such matters, how far steel cast in a sand mould was like iron cast in a sand mould; what difference there was on the surface of the steel, because it was cast in an iron ingot mould, instead of in sand, and what alteration took place in the steel by its being re-heated and passed through the rolling mill. Apart from any chemical difference, there were these differences between iron and steel, and he felt sure there was a difference of surface caused by the way in which they were manufactured.

Prof. Abe Professor F. A. ABEL said the Author had stated "that the commoner sorts of iron, containing the most phosphorus, resist corrosion far better than the superior kinds; and also that the harder steels, containing the greatest amount of carbon and phosphorus, are better in this respect than the softer and finer sorts." The Author had further remarked that the conclusions at which he had arrived from the results of experiments had been confirmed by the recent analysis of some brands of metal under consideration. The subject being one of great interest to him, he had searched the Paper, but in vain, for any facts upon which those conclusions were based. The Author had very justly stated that "It is important to ascertain how far want of uniformity in composition has to do with local corrosion in metals, and particularly in steel; also how far the presence in a medium degree, or absence in a minimum degree, of impurities in iron and steel can affect their durability." Another statement made by the Author was, "that the manufacturer and the chemist, in their anxiety to produce a metal containing the least possible amount of impurities, and thus to attain a high standard of ductility, in depriving it, perhaps, to a greater degree than necessary, of elements such as phosphorus, carbon, &c., or adding to it manganese, probably thus render it more liable to corrosion." It was stated as a probability, but further on it was given as a decided fact; and he confessed that he was unable to conjecture how the probability had been converted into a matter of certainty. The Author had made a general statement with regard to the proportions of phosphorus, carbon, and manganese in irons and steels. In regard to phosphorus, his argument might be to some extent borne out by

Prof. Abel. that statement; with reference to carbon, the proportion in steel, according to his statement, was from two to three times that existing in wrought iron, and he had given the proportion of manganese as three or four times greater in steel than in iron. He imagined that the Author wished to compare the two materials together, since, in the case of phosphorus, he had referred, not to the different proportions of phosphorus contained in one and the same material, but to the different proportions contained in the two materials. Those were the only facts bearing on the above conclusion which he had been able to find in the Papers, and as, according to these, carbon and manganese were present in larger proportion in steel than in wrought iron, he should have imagined that they ought, according to the Author's conclusions, to exert their protective influence to a far greater degree upon steel than they did upon wrought iron. That was the extent to which he had received instruction in reference to the impurities contained in wrought iron and steel, which the chemist was so anxious to remove; and he confessed the conclusion at which he had arrived was that, as regarded "assumptions and theories," the Author did not stand upon much higher level than those whom he had condemned. The Author had been very severe upon those who indulged in the view that possibly galvanic action might have something to do with the deterioration of boiler plates, whether iron or steel, but he thought there were very few persons, even among those who were not what the Author had called indiscriminate partisans of mild steel, who shared that view, and who were not convinced that even in one and the same piece of plate galvanic action might come into play very decidedly in promoting the corrosion of the metal. In reply to the possible objection that more definite results would have been obtained from more extensive trials, the Author had stated that all experiments in which the conditions were not precisely similar, could not be considered satisfactory; and Professor Abel thought there were few who had experimented with a view to obtaining precision of results, who would not most heartily agree with him in that respect. But there, again, he could not quite understand how such very strong conclusions as the Author had drawn could be based upon the results of experiments made by the distribution of large numbers of plates to different ships, in which they had received all possible kinds of treatment, especially when he found that the results of those various experiments with fifty-six sets of plates were lumped together afterwards, and that the conclusions were drawn from the average loss of weight of

Prof. Ab

the plates in those remarkably various experiments. He was one of those who considered that among the most dangerously misleading figures with which practical and scientific men could possibly have to deal were so-called averages. No doubt the results of the various experiments were interesting, as illustrating the character of the corrosion caused by different treatment, such as the water used, the different practices of blowing off, and the comparative effects of chemical agents. It was, however, from those various experiments that a definite conclusion was drawn with regard to the stability of steel as compared with iron, for the Author stated, "These results clearly prove that the conclusions arrived at by many experienced engineers and chemists as to the causes of corrosion in boilers, previous to the appointment of the Boiler Committee, were erroneous." He should have been glad if a statement of those conclusions had been given, in order that their fallacy might have been demonstrated; for he should have been most anxious to learn from such an extensive and instructive series of experiments as the Boiler Committee had the power to institute, and did institute, to what extent previously existing conclusions were wrong. The Author had also stated that "in spite of these reasonings, it is undoubtedly a fact, that under almost all circumstances iron, and particularly the harder classes, is far superior to the finer steels in its resistance to corrosion, and this the experiments described by the Author incontestably prove." That was a very strong statement, but he had no doubt that the Author had considered himself perfectly justified in making it. He must, however, pardon those who were unable, from the summary of experiments which he had given, to arrive at the same conclusion. Taking even the averages upon which the Author relied, this statement was not at all well carried out, for he could hardly consider that 10 per cent. difference in average loss would be so great in practical experiments as to constitute an "incontestable proof" of the difference between the durability of two descriptions of material. Further on he found that there was only a difference of 5 per cent. to establish the same point "incontestably." With regard to the averages of the experiments made on board the many ships, there were differences, in one case between crucible steel and Staffordshire iron, amounting to 0·3 per cent. only upon the weight of the total metal employed, and in another case between Siemens steel and Yorkshire iron of less than 1 per cent. upon the total weight. He could hardly accept results of that kind as "incontestable" proof that the superiority of iron over steel had been established. Again, in some of the special experiments made

Prof. Abel. by the Author, it had been "incontestably proved" that iron was on an equality with steel, and even that steel was superior to iron. Taking all these points into consideration, although he had read the Paper with great interest, he could not admit that the Author had in the least degree established, by the "facts" with which alone he proposed to deal, the "incontestable" superiority of wrought iron over steel as a material for boilers.

Mr. Cowper. Mr. E. A. COWPER wished to say a few words in reference to the bridge to which Mr. Matheson had alluded. He had constructed it more than thirty years ago, for the late firm of Fox, Henderson, and Co. It was in the Commercial Road, and was 120-feet span, and had been lately pulled down to increase the width of the bridge. He believed it was the first bow-and-string bridge made of iron in this country; the bow flange was of a box form, with an overhanging top section. The span of the bridge did not require that the rib should be large enough to let a man pass through. There were vertical ties and large bolts which would prevent this; therefore the box was built as air-tight as it could be—not absolutely, but so close that the air could not work in and out with freedom. In that way the inside plates, he believed, were protected very fairly, until it had been lately pulled down. Mr. Matheson had not said whether the inside plates were in a perfect condition, but he believed that they were so. In some of the outside plates, where wood had been placed against the side of the box, the iron was corroded, and in some cases very badly, no doubt from the tannic or gallic acid in the wood. But where bridges were made with laminated plates, as they were in many instances—notably in one near at hand where corrosion was going on rapidly—he imagined that in a few years there would be no plates left. It was impossible, with a number of plates riveted together, to get them all so air-tight at the edges as entirely to exclude the atmosphere, and especially the damp air coming from the chimneys of locomotives. The mode of protection suggested by Mr. Matheson was no doubt a good one, but he would suggest that a further protection should be adopted by forcing varnish or boiled oil, or whatever might be the best material, between the plates by a powerful syringe; the oil might not go all the way in, but it would go as far as the air would, and two or three injections might entirely stop the entrance of air. In that way he believed that many bridges of laminated plates which were now in a state of deterioration might be preserved from further deterioration between the plates. Thirty years was too short a life for a bridge, and some improved method of protection ought to be adopted.

Mr. W. H. **Barlow**, Past President, had noticed on railways that a very much larger corrosion of iron rails would take place in a siding which was unused, as compared with the same rails in a line which was used. The only difference he was aware of was that, where the rail was used, one of the surfaces was kept to a certain degree polished; and the theory he had formed was, that galvanic action was set up between the polished and the unpolished side. In conducting experiments of the kind to which reference had been made, the greatest possible care was required to ensure that the conditions were exactly alike. It did not appear to him to be quite satisfactory to have one plate tested in one boiler, and another in another, without knowing that the particular circumstances of each were similar. The importance of the question with reference to steel was very great: the expressions in the Paper were strong, and he thought it behoved the Institution to inquire closely into the matter, so as to be sure that the basis of operations was accurate. He was sorry his personal observations did not enable him to carry the subject farther, but it was obviously important in any comparisons that were made, that the circumstances should be similar in each case. Mr. Barl

Mr. **George Allan** said it had been his practice, during the last eight or ten years, to recommend steel for boilers, and during that period he had sent to India seventeen or eighteen steel boilers. They were 7 feet in diameter, 30 feet in length, and had been made by Messrs. Hick, Hargreaves, and Co., of Bolton, the steel having in all cases been prepared by the Bolton Iron and Steel Company. The boilers had been tested with a considerable hydraulic pressure, and in one or two cases under steam, and they were made to stand a working pressure of 100 lbs. to the square inch, the plates being $\frac{7}{16}$-inch thick, and the end-plates $\frac{9}{16}$-inch. He had not received a single complaint from India respecting any one of those boilers; he had never been asked to send out a new plate, nor had any fault been found, although it was proverbial that if anything happened in India one was sure to hear of it; so that it might be taken for granted that all was going on well. He was satisfied from his own experience that steel could certainly be depended upon for boilers. He knew of no material more reliable, from its great ductility and its good qualities in other respects. Whilst acknowledging the experiments recorded in the Paper to be interesting and important in themselves, he was of opinion that they were not properly applicable, and did not correspond to the conditions to which boilers were subject. At the same time he had observed that the softer steel plates now in use were more Mr. Alla

Mr. Allan. subject to corrosion than the harder steel plates of a few years ago, which had a tensile strength of 32 to 35 tons per square inch, as compared with 26 tons of that of the softer steel. With ordinary care and skill there was no difficulty in working the harder steel plates, but in the hands of unskilled workmen they were liable to failure. In proof of this, Messrs. Hick, Hargreaves, and Co., who were extensive users of the harder steel plates, had scarcely two of them rejected in a year. He attributed the demand for softer steel plates, which would stand any sort of treatment, chiefly to the general want of practical knowledge of the proper working of the harder quality; also to the fact that the government would have nothing else. This led to a plate being introduced less able to resist corrosion than the harder plates, which were always looked upon as able to resist corrosion better than iron. Now, it was presumed the iron and softer steel plates might be taken as about the same in this respect. An exceptional case of corrosion in a steel boiler might be met with just as in iron boilers. It had been the common practice for the last ten or fifteen years among all the leading Lancashire boiler makers to use steel plates for the furnace flues, even when they adhered to iron in preference for shells. If steel was not fitted for boilers, or was liable to excessive corrosion, he maintained it would have been found out long since; but all the leading makers had gone on using steel more extensively every year, one firm—Messrs. Hick, Hargreaves, and Co.—alone having used in the last twenty years about 12,000 tons for boilers, and with the most satisfactory results. He could not, therefore, admit that the Author's experiments, carried out as they were, in his opinion, under conditions not to be found in practice, to be of much practical value. Further in support of his views, he might point to the fact that both the Cunard and the Allan Steamship Companies had recently built the largest addition to their respective fleets—the "Servia" and the "Parisian," of 10,000 and 5000 tons—wholly of steel, including the boilers; and it was not likely the owners would have adopted steel unless they had been perfectly satisfied that it was a reliable material in all respects, including its ability to resist corrosion.

Mr. Samson. Mr. PETER SAMSON remarked that the Paper was bristling with facts which were exceedingly interesting and useful to engineers, especially to those who were entrusted with the maintenance of such structures as bridges, ships, and boilers. At the same time engineers ought to be exceedingly cautious in drawing deductions from those experiments, otherwise they might, without ground, get alarmed and scared from the use of mild steel. He

Mr. San

thought it would have added to the value of the Paper if the loss from corrosion had been given per unit of time as well as per unit of surface, because it was impossible to compare one experiment with another, or to compare the experiments with the actual corrosion going on in boilers unless that were done. He had calculated the loss of weight of the iron plates as given in the Tables per square foot of surface per month, and he had found that it averaged 55·6 grains, the greatest loss being 170 grains, and the lowest 10·9 grains. That corrosion, although it might appear large was small in amount when compared with the active corrosion going on in some boilers. Taking the average corrosion of the experimental plates as a standard by which to arrive at the durability of a ½-inch plate, 1 foot square, if corroded on one side only, he found that it would take more than two hundred years to corrode the plate entirely away. Comparing this with the average life of a well-kept marine boiler, which was only about ten years—although it was not an uncommon thing for a ½-inch plate in a boiler to be corroded away in a very few years—it was evident that the conditions under which the experiments were made, and those actually going on in boilers were entirely different; and the question arose, what effect the difference of conditions had on the results of the experiments? It was important to note that the percentage in favour of iron was 45·4 in the case of the tubes referred to in Table II., and only 10·9 in the case of the feed-water heater plates, where the rate of corrosion was about 70 per cent. greater. It would be exceedingly interesting to know the Author's views as regarded the corrosion being so little in the experimental plates compared with that in actual boilers. Referring to the experiments which the Author had made at home, he thought those results would be found useful and interesting, but they required some explanation. In those referred to as set 98 the corrosion in the first twelve months was considerably higher than that during the second twelve months, and as there was no apparent reason why it should be so, especially as the plates must have been scraped and cleaned for weighing at the end of the first period, he thought it would be useful to have the Author's explanation on that point. It would also be interesting to have his opinion as to why the corrosion in the experiments marked 102 was so much less than in those marked 98. Possibly it might be due to the water in the former series being kept in a vessel without being changed, and if that was the case it would tend to prove that the water in boilers should be blown out as seldom as possible. Referring to the experiments with the crucible

Ir. Samson. steel, it would be found that the plate which was placed in the water-butt corroded more than that placed in the tank, and that the plate in the kitchen boiler corroded less than the plate in the tank. The difference might have arisen in this way: in the water-butt, the corrosive agents were very active, owing to their not having previously come in contact with a substance for which they had an affinity, and combined freely with the experimental plates suspended therein. They were then carried on to the tank, where the second set of plates were placed, but being weakened by their first attack, less corrosion occurred, and they finally passed into the kitchen boiler weaker still, and therefore less able to combine with the last set of plates.

Mr. Giles. Mr. A. Giles, being connected with steam navigation, confessed to having had a considerable scare after reading the statements in the Paper with regard to the excessive corrosion of steel as compared with that of iron. That scare was somewhat modified by what Dr. Siemens had stated. But the two statements being so conflicting, he had applied to a gentleman who had the designing and construction of the boilers of the fleet with which he was connected (the Union Steam Company), and he had been informed that for the last three years steel had been practically adopted, instead of iron, for boilers; and that the result had hitherto been most satisfactory. The steamers ran to the Cape of Good Hope, and the boilers were worked at from 80 to 90 lbs. pressure per square inch of surface.

Mr. Woods. Mr. E. Woods said it had been stated by Mr. Matheson that the practice of preparing boiler-plates by the removal of scale had not been adopted in this country. It might be known to many members that at the London and North-Western railway works at Crewe steel had been extensively adopted in the construction of locomotive boilers, and Mr. F. W. Webb, M. Inst. C.E., had informed him that he made a great point of preparing plates in the way to which Mr. Matheson had referred: he either immersed them in a solution of sal-ammoniac or brushed them over with that solution, so as perfectly to remove the scale. The practice had been attended with excellent results, not only in enabling the joints of the plates to be made more secure and steam-tight, but also in preventing the tendency to corrosion in the interior of the boiler.

Matheson. Mr. Matheson remarked that he had referred to plates for bridges, not for boilers.

Atkinson. Mr. W. Atkinson, commenting upon the observation of Mr. Barlow as to the difference in duration of rails in use and those not in use, said the explanation might possibly be of a mechanical character.

Mr. Atl

When a rail was in use the motion of the locomotive and the carriages removed all the rusty particles, and, thus left, the surface more rapidly dried by the action of the air. It was well known that corrosion, both in wood and iron, took place in a great measure in consequence of the presence of moisture. The same explanation probably applied to the destruction of iron in a bridge where it came in contact with wood, owing probably to the increased dampness of the surface of the iron, due to the presence of wood. A similar illustration might be found in wood itself. Larch sleepers, when laid down without the bark having been taken off, deteriorated much more rapidly than those from which the bark had been removed, and he believed that was entirely due to the absorption of moisture in the bark.

Mr. Ph

Mr. D. Phillips in reply observed that his sole purpose in writing the Paper had been to lay before the Institution facts which had come to his knowledge regarding the comparative corrosion of iron and mild steel. He had no wish to depreciate mild steel. True, the Paper showed that that metal had defects; but these, he was of opinion, could be counteracted with further knowledge. It would not do the cause of mild steel any good to conceal its faults, for without clear knowledge of the defects of steel it would be impossible to remedy them. Many of the criticisms had been wide of the mark. Whilst the Paper dealt chiefly with the corrosion of iron and steel having bright surfaces, considerable time had been spent in discussing the mechanical qualities of steel, and its liability to corrode with or without black or magnetic oxide.

He could not but admire the convenient way in which Dr. Siemens had attempted to prove from the figures in the Paper that its conclusions were erroneous. Dismissing the tube and disk experiments as worthless, and skipping the experiments in the two tugs and the feed-water heater, and those with Lowmoor iron and Bolton steel, he observed that in the test of the Landore steel and the Lowmoor iron, the latter proved only 4·8 per cent. better than steel; but this was in fresh water and only for six months. Referring to Table VII. and the remarks following, he said that in this case the iron lost more than twice as much as the steel; but then the iron mentioned as having been tested in a former experiment was under trial over twice the time that the steel was. Ignoring the experiments in ocean and coast-going steamers, perhaps the most important of all to those engaged in steam shipping, Dr. Siemens proceeded to pick out from Table IX. such results as suited his purpose. In set 98, he compared the

Phillips. Landore steel with the Yorkshire iron, whilst in set 99 he compared it with Staffordshire iron. Passing over sets 100 and 101, in which both the steels gave bad results, he wound up with set 102. Now this was hardly an impartial way of treating the matter. To take into consideration only such facts as confirmed one's own opinions was a species of special pleading upon which Dr. Siemens could not be congratulated. In sets 99 and 102 the corrosion was scarcely perceptible. The D.D. 102, to which Dr. Siemens drew attention, had a patch of cinder in it, which was picked out before testing, but after it was weighed; the loss of weight should therefore have been approximately reduced. In calculating the percentages in Tables VIII. and IX., the two steels and the two irons were compared, the difference between each steel being but trifling. The results obtained, after a little over two years' trial, from the metals tested in the tube apparatus, were considered by Dr. Siemens to be valueless; but when he was better acquainted with the conditions to which the apparatus and the tubes had been subjected, this opinion would probably be modified. Mr. Phillips possessed, from a scientific point of view, only a scanty knowledge of the effects of electricity on metals; but he claimed to have a fair amount of knowledge as to the nature of corrosion in marine boilers and its causes, and he failed to see why, in the tube experiments, with metals so closely allied to each other, one metal should feel the effect of electricity more than another. He thought it would be admitted that neither in the steam chamber nor in the condensing chamber were there present conditions such as would promote galvanic action between the iron of the apparatus and the tubes, or between the tubes themselves, nor after the experiment was any such action to be perceived. At, and a little above, the water level in the condensing chamber, the tubes suffered severely, but below and above that point there was scarcely any corrosion. Again, in the steam chamber the surfaces, especially of the cold-drawn tubes, were scarcely affected. There were no disks or rods in any of these tubes. The conditions necessary to promote galvanic action inside the tubes were also absent, except perhaps in set 2, which contained salt water. The other three sets contained fresh water. In set 2, galvanic action could only take place between the iron plugs and the bottom ends of the tubes, but there were no signs of such action. If, as Dr. Siemens remarked, the common iron alone was compared with the Bessemer steel tubes, the difference was nearly 200, not 300, per cent. in favour of the iron; but in Table II. the losses in all the tubes were given, and in Table III. the losses in ten samples of each metal, under precisely similar conditions. In calculating the percentages resulting from them, he had given the true results. The tube apparatus had been designed by him at the suggestion of the Chairman of the Boiler Committee, Admiral C. Murray Aynsley, for testing tubes of various kinds of metals. Mr. Farquharson had nothing to do with it, and his remarks as to magnetic oxide showed that he did not understand the conditions under which the tubes had been tested. Mr. Phill

Mr. Phillips could not understand Dr. Siemens when he said "there were substances, compounds of iron, manganese, and silicon, sold for steel, which no doubt corroded very rapidly." The metal apparently referred to by Dr. Siemens was made by the Bolton Steel and Iron Company, on the Bessemer principle, and was considered by most practical men to be as good, in every way, as Landore steel. The weighing of the specimens in the experiments had been carefully done, chiefly by Mr. Tookey, one of the members of the first Committee, and by Mr. Ireland, one of the members of the second Committee; every plate, disk, or tube having been separately weighed.

As regarded the effect of magnetic oxide on steel, Dr. Siemens did not make it clear whether iron suffered from its oxide in the same manner and proportion as steel was said to do, nor as to the conditions under which this action took place. From what Mr. Phillips had been able to gather in this direction, the oxide could only affect a metal to which it was partially attached in salt water at ordinary temperatures, its effect in cold fresh water, and in fresh and sea water of high temperatures, such as in marine boilers, being absolutely nil. Further, every practical engineer knew only too well that this magnetic oxide in a marine boiler, especially below the level of the water, soon disappeared, much sooner, indeed, than could be wished. With the exception of the small plates, and the welded tubes, all the specimens in the experiments were effectually freed of their oxides, either by planing, filing, or grinding, so that the remarks of some of the speakers as to the black oxide were hardly to the point. According to Dr. Siemens the fact, if fact it were, that black oxide materially assisted the corrosion of steel, was a recent discovery of Mr. Barnaby, or of one of his staff, but not in connection with the working of marine boilers. Professor Williamson had, however, pointed it out to the Committee in 1874. It might prove of value to shipowners and builders, but if not it would not want companions in the limbo of neglected discoveries. The first volume issued by the Boiler Committee was full of theories as to

Ir. Phillips. galvanic action, which, with the better knowledge now existing of the working of boilers, were considered unworthy of serious consideration.

The remarks of Mr. Traill and Mr. Martell contained nothing new and nothing to comment upon, except perhaps the instance of extraordinary corrosion mentioned by the latter. Mr. Martell attributed this, as many others would do, to galvanic action between the iron rivets and the steel plates. Had the action taken place below the light water-mark, there would be some reason for attributing it to galvanic action, but in his opinion had the rivets been of the same material as the plates, a similar corrosion would have taken place. Mr. Martell had remarked, in May, 1879, "that it was not uncommon to find soft iron rivet points in iron ships somewhat pitted or worn within the surface, but the converse action of the plate wearing round the rivets was peculiar." This seemed to confirm Mr. Martell's view that the softer or purer metals did not resist corrosion so well as the harder sorts, though the action would, in such cases, be assisted by a sort of breathing or springing of the plates in a line with the rivets, especially if the plates were thinner than they would have been if of iron, by which, and friction, the paint was soon removed. Mr. Martell had no doubt often seen the sides of iron ships corroded similarly, though not to such a serious extent, after a long voyage in the tropics; he had himself seen many, amongst others two old iron hulks in Bombay harbour, completely riddled a little above the water line from the effect now of air, now of salt water, and want of attention. According, however, to the experience of Messrs. Martell, Barnaby, and Donaldson, deterioration went on in steel hulls which never occurred in iron hulls. In one case this was attributed to galvanic action between the iron rivets and the steel plates; in the other two cases to galvanic action between the steel plates and their oxides. Mr. Barnaby got over the difficulty by removing the magnetic oxide by pickling the plates, and Mr. Donaldson by galvanizing them with zinc. Why should this be necessary with steel hulls, and not with iron hulls? Practical men, he thought, would pause before they adopted either plan, and would consider how it was that the oxide on iron plates did not produce the same effect as that on steel plates.

It had been mentioned by Mr. Barnaby, not for the first time, that the results of some experiments carried out by the Admiralty contradicted those given in the Paper. In Paris, in 1878, Mr. Barnaby said that the Admiralty "had made some ex-

Mr. Philli

periments extending over four years, and although at first the pieces of steel suffered more loss than the pieces of iron, when they were put unpainted on the bottom of the ship in salt water, as time went on they discovered that the loss did not continue, and that so far as these experiments went steel was at least as good, and it appeared to him to be better, than iron."[1] In London, in 1879, he said "in the matter of oxidation in salt water, we have found by a series of trials, extending over about three and a half years, that the rate of oxidation of three plates of iron of the same brand, differed more among themselves than they differed from steel; that when the surfaces of steel plates are carefully freed from the black oxide produced in the rolls by a wash of weak acid or otherwise, the surface corrosion in salt water is very uniform; that when the surface oxide is left on, the effect of the oxide on the neighbouring bared metal is as strong and continuous as copper would be."[2] Now he was curious to know what experiments Mr. Barnaby referred to. Experiments had been made by the Admiralty with iron and steel plates at Portsmouth and at Devonport between 1874 and 1877, to test their comparative durability in sea water and in bilge water. The specimens tested and the results obtained came under the notice of Admiral Aynsley, Mr. Tookey, and himself; they ascertained that the steel plates tried at Portsmouth lost 80 ozs. 341 grains, and the iron plates 61 ozs. 52 grains, or 24 per cent. less. In the experiment at Devonport, which lasted a much shorter time than that at Portsmouth, the steel plates lost 43½ ozs., the iron plates 26½ ozs., or 64 per cent. in favour of the iron. The dockyard officers reported that the corrosion in the steel plates was more severe and irregular than in the iron. Surely these experiments were not those to which Mr. Barnaby alluded. In a letter addressed to the Controller of the Navy, dated the 6th of June, 1877, the Committee pointed out the confirmation the results obtained at Portsmouth gave to their own conclusions. He would ask, too, why these results, and those of other experiments since carried out by the Constructor's Department had not been made known? In such an important question the Mercantile Marine was as much interested as the Admiralty.

Some time had been devoted by Sir Henry Bessemer to show the different conditions to which plates suspended in boilers, and boilers themselves, were subjected. That was hardly necessary.

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[1] *Vide* The Journal of the Iron and Steel Institute, 1878, p. 429.

[2] *Vide Ibid.*, 1879, p. 53.

Mr. Phillips. One of the objects of the Committee's experiments was to ascertain the comparative endurance, as regarded corrosion, of different metals when under similar conditions, and this object they had attained. Sir Henry Bessemer had quoted Messrs. Richardson and Adamson, and it was always interesting to hear the experience of such practical men. But these gentlemen had to deal with land boilers, worked with water comparatively harmless to the materials of which they were composed. Mr. Adamson had been principally concerned with the construction of boilers; and he would ask why the results of the experience of these gentlemen, or of others, with iron boilers and steel marine boilers, had not been given? Mention had also been made by Sir Henry Bessemer of some steel boilers at Oldham, which had lasted twenty-two years, and which were now said to show no signs of corrosion, though this last remark could hardly have been seriously meant, and he opined that had these boilers been made twenty-two years ago of Staffordshire iron they would now have been in a very dilapidated condition. When the Boiler Committee visited Oldham in November, 1874, Mr. Richardson was engaged in removing and resetting iron boilers which had already done duty for more than eighteen years, and which were, he had been told, still at work. The shells of these boilers were, as usual, of ordinary iron. Again at Wigan, in 1875, he had seen some iron boilers which were more than thirty-one years old, working at pressures of from 60 lbs. to 70 lbs. to the square inch, the front ends of the flues only, over the fires, having been renewed; these, he was informed, were still at work. The following was a copy of a letter, dated 7th April, 1881, which he had received from Mr. Mason, Superintendent Engineer of the Furness Railways:—"Dear Sir—Replying to your favour of yesterday's date, the boiler of 'Firefly,' paddle steamer, Lake Windermere, was put in in 1848, that of the 'Dragonfly' in 1850; both were broken up last year. Plates (internally) good, having the bloom still on them. Boilers of 'Walney' were put in in 1868, taken out in 1878. Steel boiler completely done. Iron boiler might have lasted three or four years longer with care.—Yours, &c., R. Mason." This vessel had since been fitted with two iron boilers. In 1876 he brought with him from one of the boilers on Lake Windermere a piece of iron tube which had been in use rather more than eighteen years. On the water-side of the tubes, furnaces, &c., there was very little corrosion, but the surfaces exposed to the action of fire, sulphur and the atmosphere, had suffered a great deal, especially round the lower part of the fronts. Here were cases of iron boilers lasting over thirty years on board steamers, as well as on land. Mr. Phillip

It had been remarked by Mr. Ravenhill that if steel wasted as quickly as the specimens in set 100, " there ought now to be little of the original steel left " of the Dover boats. These boats made runs of about one hour and three-quarters' duration, allowing of their sides being examined and painted daily, if necessary, whilst the set of plates (100) were under a very severe test, and not protected—not even by their oxides; both sides of the experimental plates were wetted daily and exposed to the weather, and it was only to be supposed that they would suffer more from corrosion than plates in ships' sides painted and taken care of. He could not admit that the report received by Mr. Ravenhill from Captain Dent gave such evidence as was desirable in these matters. Indeed, he had heard that the steel boilers in the " Duke of Sutherland," one of the Holyhead boats, had suffered more than the iron boilers.

With regard to Mr. Matheson's remarks, if iron and steel were kept dry, or well looked after and painted, they would suffer but little, if any, corrosion; also with care the magnetic oxide would remain attached to the surfaces of iron structures, under ordinary conditions, for years, and would while it remained, effectually retard corrosion.

In reply to Professor Abel he contended that the results of the experiments he had described confirmed his conclusions. If the method of giving averages were unfair, the gross results would still uphold this view. He would refer any one desiring fuller information concerning the ocean plate and tube experiments, and the experiments in the tugs, &c., to the Blue Book just issued by the second Admiralty Boiler Committee (Appendices P, Q, and R). Professor Abel went on to say that since there was more carbon and manganese in steel than in iron, these elements should afford steel greater protection than iron. Carbon undoubtedly did so, but the part manganese played in this respect was doubtful, probably the reverse; taking, however, all the so-called impurities in iron and steel together, there was a greater sum total of foreign matter in common iron than in mild steel, and these foreign impurities or ingredients might be the cause of common iron corroding less than mild steel. Professor Abel said that he stated this as a fact; that was not so; he stated as a fact that the metals which contained most impurities, especially those containing the most phosphorus, resisted corrosion better than the more refined sorts. More than one scientific man supported

Mr. Phillips. the views he had advanced as to the class of metal which suffered most from corrosion; and Dr. Frankland held the same opinion as himself regarding galvanic action in boilers. He would refer to the summary of the evidence given before the Boiler Committee in 1874, by such authorities as the late Dr. Letheby,[1] Dr. A. W. Williamson,[2] Dr. E. Frankland,[3] Dr. J. Percy,[4] Mr. G. J. Snelus,[5] and Mr. W. Weston,[6] and from speeches made at the meetings of the Iron and Steel Institute in 1878–9, by Mr. I. Lowthian Bell,[7] Dr. Siemens,[8] and Mr. E. Riley,[9] and it would be seen what different conclusions such gentlemen came to. He regretted that Professor Abel should have confined his remarks to criticism without endeavouring to throw any light on the subject of the Paper.

Two of the experiments described by Mr. Phillips showed only 5 and 10 per cent. in favour of the iron, and this it was said was not "proof incontestable," that iron was superior to steel as regarded corrosion. If even these percentages were added to the 13, 20, or 25 per cent. reduction in the sectional area of steel plates and scantlings in ships or boilers accepted by the Board of Trade and by Lloyd's, which matter had been conveniently forgotten in the discussion, or if the corrosion were assumed to be equal in the metals, the result would be, if not fatal, very damaging for steel.

The greatest care was taken that the specimens in each experiment should be exposed to exactly the same treatment. With regard to the ocean-plate experiments, when fifty-six sets of test plates had been subjected to the various sorts of treatment of boilers now in practice, and furnished a percentage of 21·3 in favour of the irons over the mild steels, it was not only fair, but reasonable, to infer that iron on the whole withstood the corrosive effects of those treatments better than steel. That the treatment of boilers might be so modified as to alter this state of things he had already suggested, and indeed had often put practically to the proof.

In reply to Mr. Samson's queries regarding the results of the experiments given in Table IX., the greater corrosion in sets 98 and 100 during the first period of their trial than in the second period, was due in his opinion to the weather in the summer of

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[1] *Vide* Minutes of Evidence, p. 554. [2] *Ibid.*, p. 559. [3] *Ibid.*, p. 564.
[4] *Ibid.*, p. 640. [5] *Ibid.*, p. 630. [6] *Ibid.*, p. 144.
[7] *Vide* The Journal of the Iron and Steel Institute, 1878, p. 446.
[8] *Ibid.*, p. 457. [9] *Ibid.*, 1879, p. 106.

1879 being so much more changeable than in 1880. Mr. Samson had furnished the reply he should have given as to the greater corrosion in set 98 than in set 102, viz., that the vessel containing set 98 was much larger than that containing set 102, and that the water in it was constantly changed. The tank and boiler containing the crucible steel were small, and the water in the boiler was kept at a temperature of from 120° to 212° during about thirteen hours daily, which would account for the difference in the corrosion in the three plates. Mr. Phill

It had been calculated by Mr. Samson from some of the experiments described in the Paper, that it would take two hundred years to corrode boilers entirely away; several cases were mentioned in the Blue Book in the ocean-plate experiments, when a $\frac{3}{8}$-inch plate would be entirely gone in from two and a half to five years, while other plates would last more than thirty years, both sides of the plates being exposed to the water in the boilers. In other instances extraordinary differences would be found as regarded the amount of corrosion sustained by one metal compared with others of the same set, besides those given in the Paper. In set 24 the loss of the steels was more than twice that of the irons; in set 32 more than half as much again; in set 33 the loss of the Landore steel was more than twice that of the Bolton steel; in set 66 the steels lost nearly three times, and the Lowmoor iron nearly twice as much as the Staffordshire iron.

He had been informed that the experiments carried out and concluded some time ago by Mr. Parker, Chief Engineer Surveyor to Lloyd's, confirmed the results given in the Paper, the percentage in favour of the irons, taking all the results, being over 19, and in favour of the rough over the bright specimens 12. It was to be regretted that the conditions and results of these experiments in detail were not made known to those interested immediately they were obtained.

In conclusion he would ask why it was that iron tubes had been nearly always substituted for steel tubes in steel boilers, and why iron tubes were now put into almost every boiler, even though made otherwise of steel? Why the Admiralty should now be going back (as stated by Mr. Barnaby) to the use of iron furnaces and combustion chambers, whilst making boiler shells of steel? And why composite boilers of iron and steel should be made at all, especially by the Admiralty, after Mr. Farquharson's discovery as to the effect of magnetic oxide on steel, and the galvanic action which was asserted to be set up between iron and steel? Neither Mr. Farquharson nor Dr. Siemens threw light on the effect, if any, Mr. Phillips. of this oxide on iron, nor as to the action between iron and steel, nor between these metals and their oxides at high temperatures in marine boilers. If Mr. Farquharson's discovery, or the theories of galvanic action were to be relied on, there would by this time have been very little steel left in the composite boilers made by the Admiralty, and mentioned in the Paper. He believed that when the question as to the effect of magnetic oxide had been more practically considered, it would be found that the local corrosion was not due in iron or steel to galvanic action, but to other causes, frequently to perfect protection being afforded, for a time, to parts of the surface by the now much abused oxide, the adjoining parts being unprotected, or to want of homogeneity, or uniformity in composition, or both. When portions of surface were so protected as to be comparatively unaffected, the difference between them and the adjoining affected parts was most pointed, and to unpractised eyes very deceptive. Some of the longest-lived marine boilers had either brass tubes or back copper tube plates, or both.

Correspondence.

Mr. Adams. Mr. W. A. Adams had been a strong advocate for the use of ingot iron, especially when compressed by the Whitworth process, for gun barrels, and one of the advantages put forward by him had been the comparative freedom from oxidisation as compared with Damascus and other iron barrels. Shooting on a wet day this had been most marked, the iron barrels becoming hourly red with rust, and the steel showing little difference.

Mr. Mace. Mr. C. Mace observed that formerly he had experienced much trouble from the pitting and corroding of iron boilers. In 1878 he applied zinc plates, after the manner of the Author's patent, and from that time to the present he had had no trouble in that respect. Zinc had been applied to the boilers of twenty-one steamers under his charge, and had in every case given satisfaction.

Mr. Macnaughtan. Mr. P. Macnaughtan stated that, during the last two years, several ships belonging to the British India Steam Navigation Company had been fitted with boilers, the shells and tubes of which were of iron, and the furnaces and tube plates of steel, manufactured by the Steel Company of Scotland. These vessels were employed in India. The reports which he had from time to time received regarding the steel furnaces, &c., were very satisfactory; no corrosion had been observed upon them, and the absence of blistering, to which the highest qualities of Yorkshire iron were occasionally subject, induced him to form a favourable opinion of the use of steel for the purpose named. Mr. Mac naughta

Mr. DAVID ROWAN had been continuously making marine boilers of steel by the Siemens process since early in 1878, and was making them at present. Some of these were entirely of steel; others had outer shells of iron, and the parts exposed to the fire of steel. The steam pressures had ranged from 70 to 85 lbs. above the atmosphere. In several instances he had repeated orders from the same owners for boilers of the same material. His workmen had been singularly fortunate in flanging and working the steel plates; nothing had gone wrong in testing any of the boilers after completion, and he had not had a complaint from an owner or an engineer in charge of the machinery regarding any of the boilers made of that material. Mr. Row

Mr. W. WESTON, Admiralty Chemist, observed that it was very important, in connection with the future use of steel, that all the information known on the subject should be given; and therefore he thought it desirable to state that the results from a later series of experiments, which would be published in the report by the Committee appointed to succeed that of which the Author was a member, did not confirm those given in the Paper. On the contrary, they showed the corrosion of the two metals to be not very different, and any advantage to be on the side of steel. The discrepancy was to be explained by the fact that the experiments, relied upon by the Author, had not been free from interfering conditions; and in any comparative trial, between two metals so closely related as iron and steel, it was essential that the greatest care should be taken to ensure this. The existence of the original bloom or scale on the specimens, as in the case of the tubes tested, had been repeatedly proved by Mr. Weston to vitiate the results. Then the specimens in another series were disks placed in tubes at different levels, and therefore not under identical conditions. There was also not complete insulation between the specimens. One or other of these conditions had interfered in the experiments referred to by the Author; and that opposite results had been since obtained from experiments more carefully conducted, showed that the inference to be drawn from the Paper must not be too readily accepted. Mr. West

Mr. ROBERT WILSON observed that the Author had not dwelt upon the fact, that corrosion in boilers and ships arose from various causes—chemical, mechanical, and possibly voltaic—acting separately or in combination, and producing effects different in appearance and varying under different conditions of temperature, Mr. Wilso

r. Wilson. exposure to vibration, bending, &c. Given a certain quality of mild steel plate and a certain quality of iron plate, the latter might resist corrosion due to one cause much better than the former, whilst the comparative effect would be reversed were the corrosion due to another cause, or did it take place under different conditions. A hard iron might resist the action of a chemical agent in a gaseous form, such as the oxygen of the air contained in most feed-water, better than a ductile iron or a mild steel; but the same steel might suffer less from the action of the chemical agents in a liquid state, such as were found in the "canker" water that reached canals and brooks from iron and coal mines, or were met with in the bilge-water of some vessels.

The Paper confirmed the opinion held by many authorities who, since Mr. R. Mallet, had given much attention to the subject, viz. —that the more free the iron or steel was from foreign ingredients (however beneficially or otherwise these might affect its tenacity) the more liable it was to suffer from corrosion produced by the action of air in the presence of moisture. By a judicious selection of steel and iron specimens, according to their chemical composition, it might be shown that steel resisted corrosion better than iron, or that iron was less liable to suffer from corrosion than steel, according to the end the experimenter had in view. The knowledge of this must always cause to be regarded with a certain amount of suspicion the statements of advocates of one metal to the exclusion of the other. The Author had, however, given the results of experiments upon the irons and steels found in the market, and not prepared or selected with any interested end in view. These appeared to confirm the opinion that the most ductile steels were more liable than hard iron to suffer "between wind and water," or from the action of air in the presence of moisture.

Advocates of the use of steel need be under no apprehension of its not being ultimately adopted in preference to iron. Steel was the nobler metal, demanding and deserving more careful and intelligent treatment than ordinary iron, which it would eventually receive; and there could be no doubt that mild steel was the material of the future for ship-building and boiler-making, in spite of the dislike and prejudice still existing against its use since the injudicious attempts to employ steel of too brittle a quality twenty years ago. The advocates of steel would not, however, serve their purpose by shutting their eyes to the fact that very mild steel, under certain conditions, suffered more from corrosion than common iron, and that its homogeneous physical structure rendered it more liable than wrought iron of good quality to suffer from "tinkering" or unskilful treatment. Until the makers of steel discovered

Mr. Wils

some method of manufacture to render it more liable to resist oxidation and other kinds of corrosion, a little more care must be taken by its users for ship-building in protecting its surface. This slight extra care and additional expense would render steel more durable than iron, and result in economy in the long run. In marine boilers, steel tubes, plates, and stays, could be as efficiently protected as those of wrought iron by zinc, properly applied. It was to be regretted that the Author had not enlarged upon the proper application of zinc and the important results already obtained, having had more experience than any one else on this subject. The protection of steel, like that of iron, by electrolytic action, could only be effected by applying the zinc according to principles that ought to be more widely known. When the zinc was properly arranged, fixed, and removed, as occasion required, it would double the average life of marine boiler shells and tubes, and at the same time effect an enormous saving of fuel by allowing the boilers to be worked practically without scale. By doubling the life of marine boilers the vessels could be kept longer at sea, and therefore the same efficiency be maintained with a smaller number of vessels, whether in the Royal Navy or in the various fleets of steamers of the mercantile marine. A good deal had been said in the course of the discussion about the presence of the magnetic oxide producing galvanic action. Unfortunately the exact nature was not described of the appearance of the corrosion sought to be accounted for by this action. Whilst admitting the possibility of galvanic action being the cause of some kinds of corrosion, under certain conditions of arrangement of metals in the presence of an exciting agent, it was extremely doubtful whether such corrosion could not have been equally well accounted for by chemical action alone, or assisted in some cases by mechanical action. The questionable habit of seizing upon galvanic action to account for corrosion had outlived that of dragging in electricity to account for the explosion of a boiler whenever one of those disasters occurred. Referring to the effect of the magnetic oxide on steel plates, it could not be denied that as long as this magnetic oxide remained intact it formed about as good a protection as possible against the attack of air when once the plate was permanently immersed in water. It was only when it was partially removed that the magnetic oxide was said to act injuriously. Now, strange to say, in the cases he had seen where the scale of magnetic oxide was adhering loosely to the plates, it still protected, to some extent, the plate underneath, where it might be expected its injurious effect would be most severely felt. Where this scale had fallen off, the plate was certainly suffering from uniform corrosion, but not worse than

r. Wilson. other plates free from oxide where the paint had been rubbed off. In his opinion the effect of the magnetic oxide was more apparent than real. In the first place, where one portion of a plate only was protected by magnetic oxide, the unprotected portion appeared more corroded by contrast, especially when the oxide scale was not lying close to the plate. In the second place, when the magnetic oxide fell off it took the coating of paint with it, and a portion only of plate being bare, it was in a worse position than if the whole plate were bare, as there was a concentrated destructive action at the exposed part. Suppose a side of a house were cemented to keep out the damp, and a portion of the cement became detached during very bad weather, the effect was a damp spot on the paper inside, apparently more severe than the general dampness visible there before the outside was cemented. It would be unreasonable to say that the presence of the cement contributed to the dampness, or that it had an effect corresponding to galvanic action in the case of the magnetic oxide on the portion of the steel plate. In both cases the effect was apparently greater by contrast, and in reality greater by a concentration at one spot of the action than would be present in the absence of all scale or cement. By pickling the plates and removing the magnetic oxide before painting, the possibility was prevented of a patch of magnetic oxide falling off with the paint and leaving the plate completely exposed. This reduced the chance of the plate becoming bare and suffering from chemical action, whether induced and assisted or not by jarring, springing, or attrition. The corrosion that occurred with steel plates near the iron rivets often employed to make the joints, was frequently ascribed to galvanic action. When countersunk rivets were used, it might be expected that any effect due to galvanic action would be most severe at the line of contact between the rivet head and the plate, in the shape of a groove close round the rivet head. But the corrosion in the cases which he had examined was greater half-way between the rivets than where the plates touched them. In fact, the rivet seemed to protect the plate close to it, whether the head was countersunk or not, and that was scarcely what would be expected if voltaic action were the cause. But the same effect had been noticed with iron plates and iron rivets, and in some cases where iron rivets were used with steel plates, the rivet heads suffered before the plates were affected. Was this due to galvanic action also?

r. Phillips. Mr. D. Phillips, in reply to the correspondence, was pleased to hear such good accounts of Mr. Mace's boilers and of the steel furnaces and tube plates in the British India Company's boilers. If the last-named boilers were fitted with zinc on the plan recom-

Mr. Philli

mended by him, as he believed most of the Company's boilers on the main lines had been, and were treated in the same manner and with the same care, he thought the Company would have little to fear.

The remarks of Mr. Weston were a complete surprise to him. In answering them he should only appeal to the report of the Committee of which Mr. Weston was a member. The specimens in all the experiments but two conducted by the first Committee were thoroughly freed of their oxides, not by the uncertain process of pickling, but by planing, filing, or grinding. It would be supposed, from the remarks of Mr. Weston, that the same course was pursued by the Committee of which he was a member. On turning, however, to the report of this Committee, it would be found that the M series of experiments were made with pieces of metal, half of which were freed of their oxides by pickling, and half with as much of their oxides on as their preparation would admit, and that in the N series of experiments none of the specimens were freed of their oxides. These experiments showed that no comparison could be made with such small areas of surface between metals retaining their oxides. In the steam space of tube 1, series M, where galvanic action could not possibly take place, the metals lost 70·2 grains in sixty-six days (1st period), and 72·9 grains in sixty-one days (2nd period); in the steam space of tube 3, they lost 341·4 grains in sixty-six days, and only 82·1 grains in sixty-one days. To what could this difference be due but to the condition of the surfaces at starting and the removal of the oxide during the first period? In tube 1 the testing pieces were all of iron, eight in number; in tube 3 an equal number of iron and of steel, four of each. Both the tubes contained sea-water. The results of the M and N series proved also, and satisfactorily, that the oxides, instead of affecting, protected the metals to an extraordinary degree. The difference, in some of the groups, between the losses in the pickled and the rough specimens in sea-water was considerable; but in fresh water, where no galvanic action could take place, the pickled plates in some of the groups had lost three, four, and over five times as much as those not freed of their oxides, under exactly similar conditions (in the same tube and at the same level). In tube 9, just below the level of the water, the four pickled iron plates lost 288·4 grains, the four rough plates only 54·2 grains; in the group below this the pickled plates lost 217·4 grains, the rough plates only 62·5 grains. In tube 14, again, with an equal number of steel specimens, the four pickled plates just below the level of the water lost 331·6 grains, the four rough plates only 87 grains; in the bottom group the

r. Phillips. pickled plates lost 178·1 grains, the rough plates only 69·1. Both tubes, 9 and 14, contained fresh water. Taking these facts and the short time of trial, four months only, into consideration, it would hardly be allowed that these were "experiments more carefully conducted" which contradicted the results of those carried out by the first Committee. The K series of experiments were made with polished disks prepared by the first Committee, and the results from two groups in eight tubes (one iron and one steel disk in the steam space, and two iron and one steel a little below the level of the water) as stated on p. 86 of the report of the second Committee, give a percentage in favour of the iron, taking both groups, of nearly 20, in the steam space of 8·7, and below the level of the water of 10·4, after seven months' trial. Although the metals were insulated and the groups placed at corresponding levels in the tubes, the results appeared to be considered by Mr. Weston and the second Committee unreliable. Nevertheless, this was the only series conducted by them in which the losses of the metals could be accurately ascertained.

With most of Mr. Wilson's remarks he entirely concurred. Mr. Wilson possessed a vast amount of practical knowledge regarding corrosion, especially in boilers. He trusted that his anticipations as to the future of mild steel would be realised; but this would depend on the care taken by the manufacturer and the chemist to produce a metal reliable, at all times of uniform quality and composition, and capable of resisting the most severe corrosion, and withstanding vibrations and shocks, as well as, if not better than, ordinary iron. He had not endeavoured in the Paper to deal with the causes of corrosion, or the protection of metals from corrosion, but simply with the relative durability of the metals found in the market. He trusted also that what he had shown might be of some good, even if it only induced manufacturers and consumers to be more cautious, and not to think a cause won before the battle was half fought.

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29 March, 1881.

JAMES ABERNETHY, F.R.S.E., President,
in the chair.

The discussion upon the Paper "On the Comparative Endurance of Iron and Mild Steel when exposed to Corrosive Influences," by Mr. David Phillips, occupied the evening.

5 April, 1881.

JAMES BRUNLEES, F.R.S.E., Vice-President,
in the Chair.

The following Associate Members have been transferred by the Council to the class of

Members.

EDWARD DOBSON.
WILLIAM GILL.
ALEXANDER IZAT
NIEL MCDOUGALL.
EDWARD JOHN TATAM.
CHARLES RITCHIE WALKER.

The following Candidates have been admitted by the Council as

Students.

RODOLFO ARAUZ.
ALAN BREBNER, Jun.
ARTHUR HENRY BUTLER.
ROSS CHISHOLM.
HERVIC GRAHAME COBBE.
HARRY COLLINS.
WALTER JOHN CORNISH.
CHARLES HEYLAND FOX.
JOHN EBEN HALL.
WILLIAM ROBERT PAUL HEDERSTEDT.
HARRY AUBREY HOFFMEISTER.
HENRY CHARLES TERRETT HUNT.
CHARLES EUSTACE LE FEUVRE.
JAMES MELDRUM.
CHARLES KELLOCK MATHEWS.
ALFRED MONROY MONTANARO.
WILLIAM PEEK.
NORMAN WILLIAM ROY.
STUART ARTHUR RUSSELL.
WALTER TAYLOR.

The following Candidates were balloted for and duly elected as:—

Members.

HENRY JOSEPH BUTTER.
ANDREW FOOTE.
SAMSON FOX.
JAMES HENRY GREATHEAD.
TIMOTHY HARRINGTON.
EDWARD PRITCHARD MARTIN.
JOHN RAMSDEN.
EDWARD WINDSOR RICHARDS.

Associate Members.

PERCY RUSKIN ALLEN, Stud. Inst. C.E.
JOHN ANDERSON.
BENJAMIN HILLIER ANTILL.
JOHN BOWEN.
SULYARDE BERNARD CARY.
ALFRED COLLETT.
HASTINGS CHARLES DENT, Stud. Inst. C.E.
CHARLES EDWARDS WILLOUGHBY DODWELL, B.A.
ALFRED GENT.
JAMES LENNOX HOUSTON.
JOHN BIRCH MINCHIN.
WILLIAM DE NORMANVILLE.
ROLAND PERRIER.
WILLIAM SHEARS, Jun., Stud. Inst. C.E.
JOHN CAMPBELL THOMPSON.
ILLIUS AUGUSTUS TIMMIS.
FREDERICK HARVEY TREVITHICK.
CLAUDE ST. MAUR WILLIAMS, Stud. Inst. C.E.
CHARLES HUMPHREY WINGFIELD.

(*Paper No. 1759.*)

"The Actual Lateral Pressure of Earthwork."

By BENJAMIN BAKER, M. Inst. C.E.

THE fact that a mass of earthwork tends to assume a definite slope, and that if this tendency be resisted by a wall or any other retaining structure, a lateral pressure of notable severity will be exerted by the earthwork on that structure, must have enforced itself upon the attention of constructors in the earliest ages. Many of the rudest fortresses doubtless had revetments, and of the hundreds of topes, or sacred mounds, raised in India and Afghanistan two thousand years ago,[1] not a few afford examples of surcharged retaining walls on as large a scale as those occurring in modern railway practice. Nevertheless, long as the subject has occupied the attention of constructors, there is probably none other regarding which there exists the same lack of exact experimental data, and the same apparent indifference as to supplying this want. Thousands of pieces of wood have been broken in all parts of the world to determine the transverse strength of timber, whilst the experiments that have been undertaken to ascertain The Actual Lateral Pressure of Earthwork are hardly worth enumerating. One authority after another has simply evaded the task of experimental investigation by assuming that some of the elements affecting the stability of earthwork are so uncertain in their operation as to justify their rejection, and have so relieved themselves from further trouble. It would hardly be less logical to assume that because timber is liable to become rotten and possess no strength at all, it was therefore unnecessary to conduct experiments in that case also. As a matter of fact, although these uncertain elements are neglected in investigations, engineers in designing, and still more contractors in executing, works, do not neglect them, nor could they do so without leading to a blameworthy waste of money in some instances, and to a discreditable failure in others. The result of the present want of experimental data is then simply that individual judgment has to be exercised in each instance without that aid from careful experimental investigation which in these times is enjoyed in almost every other branch of engineering.

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[1] *Vide* "The Illustrated Handbook of Architecture." By James Fergusson, chapter ii.

The mass of existent literature on the subject is both misleading and disappointing, for with little exception[1] the bulk of it consists merely of arithmetical changes rung upon a century-old theory, which even at the time of its inception was put forward but as a provisional approximation to the truth pending the acquirement of the necessary data. Writing some fifty years ago, Professor Barlow excused his "very imperfect sketch of the theory of revetments, at least as relates to its practical application," on the ground that there was a "want of the proper experimental data";[2] and but comparatively the other day Professor Rankine had to write almost in identical terms:[3] "There is a mathematical theory of the combined action of friction and adhesion in earth; but for want of precise experimental data its practical utility is doubtful." It is not, therefore, for want of asking that the missing data are not forthcoming. Indeed, the present desiderata could not have been more clearly formulated than they were half a century ago by Professor Barlow in the following words: "To render the theory complete, with respect to its practical application, it is necessary to institute a course of experiments upon a large scale; upon the force with which different soils tend to slide down when erected into the form of banks. A well-conducted set of experiments of this kind would blend into one what many writers have divided into several distinct data. Thus some authors have considered first, what they call the natural slope of different soils, by which they mean the slope that the surface will assume when thrown loosely in a heap; very different, as they suppose, from the slope that a bank will assume that has been supported, but of which that support has been removed or overthrown. This, therefore, leads to the consideration of the friction and cohesion of soils, and what is denominated the slope of maximum thrust; but however well this may answer the purpose of making a display of analytical transformations, I cannot think it is at all calculated to obtain any useful practical results. I should conceive that a set of experiments, made upon the absolute thrust of different soils, which would include or blend all these data in one general result, would be much more useful, as furnishing less causes of error, and rendering the dependent computations much more simple and intelligible to those who are commonly interested in such deductions."

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[1] *Vide* Considère, in "Annales des Ponts et Chausées," 1870. Rankine, in "Phil. Trans. of the Royal Society," 1857. Curie, in "Comptes rendus de l'Académie des Sciences," 1873.

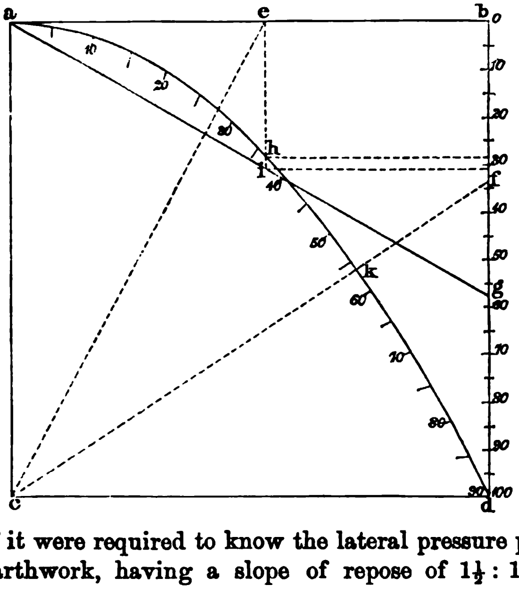
[2] *Vide* "A treatise on the Strength of Materials," 5th edition, p. 115.

[3] *Vide* "A Manual of Civil Engineering."

A knowledge, however imperfect, of The Actual Lateral Pressure of Earthwork, as distinguished from what may be termed the "text-book" pressures, which, with hardly an exception known to the Author, are based upon calculations that disregard the most vital elements existent in fact, is of the utmost importance to the engineer and contractor. It affects not merely the stability of retaining walls, but the strength of tunnel linings, the timbering of shafts, headings, tunnels, deep trenches for retaining walls, and many other works of every-day practice. The vast divergence between fact and theory has perhaps impressed itself with peculiar force upon the Author, because, having had the privilege of being associated with Mr. Fowler, Past-President Inst. C.E., during the whole period of the construction of the "underground" system of railways, he has had the advantage of the experience gained in constructing about 9 miles of retaining walls, and, in relation to the subject of the present Paper, the still more valuable experience of 34 miles of deep-timbered trenches for retaining walls, sewers, covered ways, and other structures. A timber waling is a sort of spring, rough it may be, but still the deflections when taken over a sufficiently large number of walings afford an approximate indication of the pressure sustained—an advantage which a retaining wall does not possess. Again, though numberless retaining walls have failed, in ninety-nine cases out of a hundred the failures have been due to faulty foundations, and, consequently, experiences of this sort seldom afford any direct evidence as to The Actual Lateral Pressure of Earthwork. In timbered trenches, on the other hand, the element of sinking and sliding foundations does not so frequently arise to complicate the investigation.

All kinds of earth were traversed by the above 34 miles of trenches, from light vegetable refuse to the semi-fluid yellow clay which at different times has crushed in so many tunnel linings in the northern districts of the metropolis. The heights of the retaining walls ranged up to 45 feet, the depths of the timbered trenches to 54 feet, and the ground at the back of the former was in many cases loaded with buildings ranging up to 80 feet in height. Possibly some of the Author's observations and conclusions in connection with these and other works of a similar character may be of interest to engineers, though the information he is able to contribute, having been obtained chiefly in the ordinary routine of his practice and not in specially devised investigations, must necessarily form but a very imperfect contribution to the data which have been asked for so long.

The theory underlying all the multitudinous published tables of required thickness for retaining walls is, that the lateral pressure exerted by a bank of earth with a horizontal top is simply that due to the wedge-shaped mass included between the vertical back of the wall and a line bisecting the angle between the vertical and the slope of repose of the material. If this were true in practice, all such problems could be solved by merely drawing a line on the annexed diagram, in which *a b d c* is a square, *a b g* a triangle, having sides of the ratio of 1 : $\sqrt{\frac{1}{3}}$, and *a h d* a parabolic curve.[1]



Thus, if it were required to know the lateral pressure per square foot of earthwork, having a slope of repose of 1½ : 1, and the thickness of rectangular vertical wall which, when turning over on its outside edge would just balance that pressure, it would merely be necessary to draw the line *c f* at the given slope of

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[1] For earthwork and masonry of the same weight per cubic foot the equation for stability is—

$$\frac{h\,t^2}{2} = \frac{h^3}{6} \tan^2 \tfrac{1}{2} \text{ angle.}$$

Hence, the required thickness (t_1) in terms of the height (h) will be—$t_1 = \sqrt{\frac{1}{3}}$ tan ½ angle, which is represented on the diagram by the line *a—g*; and the "equivalent fluid pressure" in terms of that of a cubic foot of earthwork will be = $\tan^2 \frac{1}{2}$ angle, which is represented by the parabolic curve *a h d*.

$1\frac{1}{2} : 1$ and the line $c\,e$ bisecting the angle $a\,c\,k$, when the line $e\,h$ would give the equivalent fluid pressure in terms of that of a cubic foot of the earth = 28·7 per cent., and the line $e\,i$ the thickness of the rectangular wall in terms of the height = 31 per cent., the weight of masonry being the same as that of the earth.

Common stocks in mortar, and ballast backing, each weigh about 100 lbs. per cubic foot, hence, on the preceding hypothesis, the pressure acting on the wall would be the same as that due to a fluid weighing 28·7 lbs. per cubic foot. If, as is usually the case, the masonry be heavier than the earthwork, the required thickness of wall would be reduced in inverse proportion to the square root of the respective weights, so that should the masonry weigh 10 per cent. more than the ballast, the thickness would be about 5 per cent. less than before, or, say, 29·5 per cent. of the height.

For other slopes of repose the equivalent fluid pressure and thickness of wall for materials of equal weight would be as follows:—

Ratio of horizontal to vertical	·5	·6	·7	·8	·9	1·0	1·1	1·2	1·3
Fluid pressure . . .	5·6	7·7	10	12·4	14·8	17·2	19·6	22	24·3
Thickness	·136	·160	·182	·203	·222	·239	·256	·27	·284

Ratio of horizontal to vertical	1·4	1·5	1·6	1·7	1·8	2	3	4	∞
Fluid pressure . . .	26·5	28·7	30·7	32·8	34·6	38·2	52	61	100
Thickness	·297	·31	·32	·33	·34	·357	·416	·451	·578

In the thickness tabulated above no allowance has been made for the crushing action on the outer edge; in practice the batter usually given to the face of the wall more than compensates for this action if the mean thickness be that given in the Table. No factor of safety is included, but according to theory the wall in each case would be just on the balance. Any one accustomed to deal with works of this class will, however, know that in practice walls so proportioned would in the majority of cases possess a large factor of safety.

Doubtless many engineers will, with the Author, have noticed that labourers and others not infrequently carry out unconsciously a number of valuable and suggestive experiments on The Actual Lateral Pressure of Earthwork. In stacking materials, rough-and-ready retaining walls, made of loose blocks of the same material, are often run up, and as it is generally of little moment whether a slip occurs or not, the workmen do not trouble about factors of safety, but expend the least amount of labour that their every-day experience will justify, and so a tolerably close measure is obtained of the average actual pressure of material retained. When the wood-paving was recently laid in Regent Street, the space being limited, the stacked wooden blocks in many cases had to do duty as retaining walls to hold up the broken stone ballast required for the concrete substructure. In one instance (Ex. 1) the Author noted that a wall of pitch-pine blocks, 4 feet high and 1 foot thick, sustained the vertical face of a bank of old macadam materials which had been broken up, screened, and tossed against this wall until the bank had attained a height of 3 feet 9 inches, a width at the top of about 5 feet, and slopes on the farther sides deviating little from 1·2 to 1. Now, referring to the diagram and Table of thicknesses, it will be seen that according to the ordinary theory the thickness of wall which would just balance the thrust of a bank 3 feet 9 inches high of material having a slope of repose of 1·2 to 1 would be $3 \cdot 75 \times \cdot 27 = 1 \cdot 01$, or, say, 1 foot, which is the actual thickness of the given wall. But in the Table the specific weight of the material in the wall and backing is assumed to be the same, whereas in the present case the weight of the pitch-pine block wall, allowing for the height being greater than that of the bank, would only be, say, $46 \text{ lbs.} \times \frac{4 \text{ feet}}{3 \cdot 75 \text{ feet}} = 49$ lbs. per cubic foot, whilst that of the broken granite bank would be, say, 168 lbs. less 40 per cent. for interstices = 101 lbs. per cubic foot. It follows, since the wooden wall stood, that if it had been made of materials having the same weight per cubic foot as the bank, the retaining wall would not have been on the point of toppling over, as the ordinary theory would indicate, but have possessed a factor of safety of at least $\frac{101 \text{ lbs.}}{49 \text{ lbs.}}$, or, say, 2 to 1. The effective lateral pressure of the earthwork in this instance consequently could not have exceeded a fluid pressure of $\frac{22 \text{ lbs.} \times 49}{101} = 10 \cdot 7$ lbs. per cubic foot, instead of the 22 lbs., which theoretically corresponds to the given slope of 1·2 to 1.

Taking another case, in which the wall, instead of being lighter than the bank, was much heavier, the same conclusion still holds good. In this instance (Ex. 2) the Author found a wall of slag blocks having a batter of $\frac{1}{8}$ of the height, and an effective thickness of 1 foot sustained a bank of broken slag 10 feet high, with a surcharge of some 5 feet more. The battering wall, with a thickness of $\frac{1}{10}$ of the height, would have the same stability as a vertical wall 0·173 thick, and the lateral pressure of the surcharged bank with the battering face would be practically the same as that of a horizontal-topped bank with a vertical face; hence, since the relatively closely-packed slag blocks constituting the wall would weigh about 40 per cent. more than the broken slag of the bank, the thickness of a vertical wall built of materials of the same weight as the bank, and having the same stability as the wall under consideration would be $= \sqrt{1 \cdot 4} \times 0 \cdot 173 = 0 \cdot 205$ of the height. Referring to the Table, the figure 0·205 will be found to apply to a slope of repose of 0·8 to 1, whereas the actual slope in the instance of this slag was 1·33 to 1. For the latter slope the thickness theoretically should have been 0·29, and since the stability varies as the square of the thickness, it follows that with the thickness indicated by theory, the wall, instead of being just on the balance, would have possessed a factor of safety of at least $\frac{0 \cdot 29^2}{0 \cdot 205^2}$, or 2 to 1, as in the last example.

Other instances of these unintentional experiments on the lateral pressure of earthwork will be found in the stacking of coal in station yards, in the rubbish banks at quarries, and in many other instances which have been investigated by the Author, with the invariable result of finding that walls which, according to current theory, would be on the point of failure, really possess a considerable factor of safety.

Turning now from indirect to direct experiments, specially arranged with a view to determine the lateral pressure of earthwork, those carried out at Chatham nearly forty years ago by Lieutenant Hope, R.E., may be referred to. His intention was to experiment first with fine dry sand, as free as possible from the complications introduced by cohesion, irregularities of mass and other practical conditions, and then to extend the investigation to ordinary shingle, and to clay and other soils possessed of great tenacity. Sand and shingle were, however, alone experimented with.

The direct lateral thrust of sand weighing 91 lbs. per cubic foot when lightly thrown together, and 98½ lbs. when well shaken, was measured by balancing the pressure exerted on a board 1 foot square. The mean results of seven experiments (Ex. 3) was 9 lbs. 7 oz., which is that due to a fluid weighing nearly 19 lbs. per cubic foot. As the slope of repose of the sand employed was 1·42 to 1, the theoretical fluid pressure due to the weight of 98½ lbs. per cubic foot would be 26·2 lbs., or about 40 per cent. more than the observed 19 lbs. per cubic foot.

With gravel (Ex. 4) weighing 95½ lbs. per cubic foot, and having a slope of repose of 1⅓ to 1, about the same lateral pressure was found to exist. Lieutenant Hope attempted to reconcile the difference between theoretical and actual results by adding to the measured force an estimated sum for friction against the sides of the apparatus, but experiments of the Author's, to be subsequently referred to, clearly prove that the difference is not to be so accounted for. Indeed, the knowledge of what the pressure theoretically should be would appear to have given Lieutenant Hope an unconscious bias in the direction of rather exaggerating the experimental results. This it is extremely easy to do, as a trifling amount of vibration will alter the pressure from 10 to 50 per cent., and a comparatively innocent shake in a small model will correspond in its relative effects with an earthquake in real life.

Experiments with coloured sand in a vessel with glass sides did not uniformly confirm the usual theory that the angle of pressure of maximum thrust is half that contained between the natural slope and the back of the wall (Ex. 5). Thus the line of separation was at an angle of 24° with the vertical instead of 28°. Again, with a gravel bank (Ex. 6) 10 feet high the line of separation ranged from 3 feet 8 inches to 5 feet 8 inches from the back of the wall, whilst as the natural slope was 1⅓ to 1, the distance should have been 5 feet in all instances if Coulomb's theory applied strictly to even such exceptionally favourable materials as dry sand and shingle.

The really valuable portion of Lieutenant Hope's investigation was the series of experiments on walls built of bricks laid in wet sand. The first of these (Ex. 7) was about 20 feet long and two-and-a-half bricks, or say, 1 foot 11 inches thick. When raised to a height of 8 feet and backed with ballast, it had inclined from the vertical about 1½ inch; at 9 feet the inclination had increased to 3¼ inches, and at 10 feet the wall fell forward in one mass. At the instant when the thrust of the ballast overcame the stability of the wall, the overhang must have been 4 inches, and the moment of stability per lineal foot certainly not more than 2,000 lbs. × 0·9 foot = 1,800 foot-pounds. Hence, dividing by $\frac{h^3}{6}$, is obtained 10·8 lbs. per cubic foot as the weight of the fluid, which would have exerted a lateral pressure equal to that of the ballast piled against this 10-feet wall. This is hardly more than half the pressure obtained with the 1-foot square board, and shows how desirable it is that even the most faithful experimenter should not know what to expect if a mere shake of a table will enable him to obtain the desired result. The natural slope of the ballast being 1⅓ to 1, and the weight 95½ lbs. per cubic foot, the pressure theoretically should have been 23·6 lbs. per cubic foot instead of 10·8 lbs.; hence a wall so proportioned as to be on the point of toppling over, according to the ordinary theory, would in this instance have had a factor of safety of rather more than 2 to 1.

Another vertical wall (Ex. 8) was constructed with the same amount of materials differently disposed. At 8 feet high, after heavy rain, the 18-inch thick panel between the 27-inch deep counterforts had bulged 1¼ inch; at 12 feet 10 inches the bulging had increased to 4½ inches, and the overhang at the top to 7½ inches, when, after some hours' gradual movement, the wall fell. The moment of stability at the time of failure could not have exceeded 2,600 lbs. × 1 foot = 2,600 foot-pounds, which, divided by $\frac{h^3}{6}$, gives 7·4 lbs. per cubic foot, instead of the theoretical 23·6 lbs., as the weight of the equivalent fluid. This result is clearly not evidence that the pressure of the ballast was less in the counterforted wall than in the wall of uniform thickness, but that the binding of the ballast between the counterforts increased the stability of the wall by practically adding somewhat to its weight.

A wall with a batter of ⅕ of the height, and with counterforts of the same thickness as the last (Ex. 9), was next tried, with noteworthy results. This wall, only 18 inches thick, with counterforts 3 feet 9 inches deep, measuring from the face of the wall, and 10 feet apart, was carried to a height of 21 feet 6 inches without any indications of movement, beyond a bulging about halfway up of 2½ inches at the panel, and 1½ inch at the counterfort; and in Lieutenant Hope's opinion it would probably have stood for years without giving way any more, although the mean thickness was less than $\frac{1}{10}$ of the height. The calculated stability indicates that a fluid pressure of 8·5 lbs. per cubic foot would have overturned the wall, and, correcting for the reduced thrust of the ballast due to the batter of its face, the equivalent pressure on a vertical wall would be that of a fluid weighing 10 lbs. per cubic foot.

Here, again, doubtless the binding of the gravel between the counterforts contributed to the stability of the wall; but, even adopting the extreme and impossible hypothesis that the ballast was as good as so much brickwork, or, in other words, that the wall was a monolithic structure of the uniform thickness of 3 feet 9 inches, its stability would barely balance the 23·6 lbs. per cubic foot fluid pressure theoretically due to the weight and slope of repose of the backing. Assuming that the binding of the ballast between the counterforts increased the stability, as in Examples 8 and 9, by about 45 per cent., the fluid resistance would be 14·5 lbs. per cubic foot; and, remembering that this wall did not fall, though the bricks were only laid in sand, it is reasonable to infer that this interesting experiment confirms the previous conclusion that a properly built wall in mortar or cement, just balancing the theoretical pressure, would really have had a factor of safety of 2 to 1. Other experiments of Lieutenant Hope's justify this inference, and so do the experiments of General Pasley, also made at Chatham many years ago.

General Pasley[1] experimented with loose dry shingle weighing 89 lbs. per cubic foot, and having a natural slope of 1¼ to 1. His model retaining walls (Ex. 10) were 3 feet long, 26 inches high, of various forms and thickness, and weighed 84 lbs. per cubic foot. The stability of each wall was tried by pulling it over by weights before and after backing it up with shingle, and the difference between the two pulls of course represented the thrust of the shingle. When the thickness of the vertical wall was 8 inches, the stability, without shingle, was equivalent to a pull of 47 lbs. applied at the top of the wall, and with shingle, the pull required to upset it was reduced to 30 lbs. The difference of 17 lbs. represents the thrust of the shingle, and throughout the several hundreds of experiments this appears to have been comprised within the limits of 16 lbs. and 24 lbs. The centre of pressure being at ⅓ of the height of the wall, the mean thrust of 20 lbs. at the top will be equivalent to 60 lbs. at the centre of pressure, and the area being 6·5 square feet, and the height 26 inches, the actual lateral pressure of the shingle, as deduced from General Pasley's experiments, is equivalent to that of a fluid weighing 8·5 lbs. per cubic foot, instead of 21 lbs. as theory would indicate.

General Cunningham tested some model revetments, and his experiments led him to believe that General Pasley had over-estimated the thickness required for stability. The models, in this case about 30 inches in height, were weighted with earth and musket-bullets to the equivalent of an equal mass of masonry weighing 129 lbs. per cubic foot. One of the models (Ex. 11) represented a wall 30 feet high, 6 feet thick at the base, vertical at the back, battering 1 in 10 on the face, with counterforts 4 feet 3 inches thick, 18 feet from centre to centre, and of a depth equal to the thickness of the wall, or say, 3 feet at the top and 6 feet at the base. This was backed up and surcharged with shingle weighing 104 lbs. per cubic foot, but required a pull of 111 lbs. to overturn it. Another model (Ex. 12) representing a wall 18 feet high, 4 feet 4 inches thick at the base, and 2 feet 8 inches thick at the coping, without counterforts, when surcharged with shingle to a height greater than that of the wall, required a pull of 84 lbs. to upset it. A fluid pressure of 19 lbs. per cubic foot would overcome the stability of such a wall; hence, having regard to the surcharge and to the pull, it will be found that the actual lateral pressure of the shingle could not have exceeded that due to a fluid weighing 8 lbs. per cubic foot.

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[1] *Vide* "A course of Elementary Fortification." By Major-General Sir C. Pasley.

General Burgoyne also commenced an experimental investigation of the question of retaining walls, but circumstances precluded his pursuing the subject. About half a century ago he built at Kingstown four experimental walls 20 feet long and 20 feet high, having the same mean thickness of 3 feet 4 inches, or $\frac{1}{6}$ of the height, but differing otherwise. One of them (Ex. 13) was of the uniform thickness of 3 feet 4 inches, and battered $\frac{1}{6}$ of the height; another (Ex. 14) was 1 foot 4 inches thick at the top, and 5 feet 4 inches at the bottom, with a vertical back; the third (Ex. 15, Fig. 1) was of the same dimensions, with a vertical front; and the last (Ex. 16, Fig 2) was a plain rectangular vertical wall *3 feet 4 inches* thick. The masonry consisted simply of rough

FIG. 1.

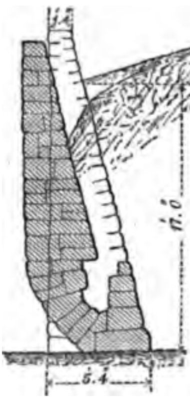
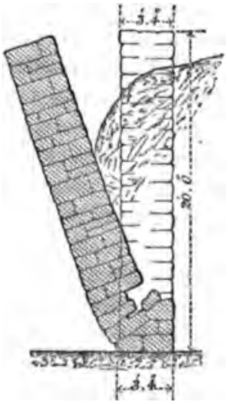


FIG. 2.



granite blocks laid dry, and the filling was of loose earth filled in at random, without ramming or other precautions, during a very wet winter. No. 1 wall stood perfectly, as might have been expected from the behaviour of Lieutenant Hope's experimental wall of nearly the same height and batter. No. 2 wall also stood well, coming over only about 2 inches at the top. A fluid pressure of 22·5 lbs. per cubic foot would be required to overcome the stability of this dry masonry wall weighing 142 lbs. per cubic foot. Earthwork of the class described, consolidated during continuous rain, would not weigh less than 112 lbs. per cubic foot, nor have a slope of repose less than 1½ to 1. Referring to the Table, the theoretical pressure of such earthwork would be 28·67 × 1·12 = 32 lbs. per cubic foot, or nearly one-half greater than the wall could resist.

No. 3 and No. 4 walls both fell when the filling had attained a height of 17 feet. The former came over 10 inches at the top, was greatly convex on the face, overhanging 5 inches in the first 5 feet of its height and rending in every direction, when finally it burst out at 5 feet 6 inches from the base, and about two-thirds of the upper portion of the wall descended vertically until it reached and crushed into the ground (Fig. 1). The vertical wall tilted over gradually to 18 inches and then broke across, as it were, at about ¼ of its height and fell forward (Fig. 2). So long as the wall remained vertical the calculated stability would indicate it to be equal to sustain the pressure of a fluid weighing 20·4 lbs. per cubic foot, but the overhang of 18 inches and the bulging which occurred would reduce the stability exactly one-half, so that a fluid pressure of 10·2 lbs. would really have sufficed to effect the final overthrow. The character of the failure both of No. 3 and No. 4 walls clearly indicates that if the walls had been in mortar or cement, as usual, the overhang would not have been a fraction of that occurring with the dry stone walling, and the failure would not have taken place. Since, as already stated, the theoretical thrust of the earthwork would be 32 lbs. per cubic foot, it is hardly unfair to conclude that a wall in mortar and proportional to that pressure would not have come over and would have enjoyed a factor of safety of at least 2 to 1.

Colonel Michon carried out in 1863 an interesting experiment (Ex. 17) on a 40 feet high retaining wall of a peculiar type (Figs. 3 and 4), which perhaps may be best described as a very thin wall with numerous battering buttresses turned upside down. The face wall, battering 1 in 20, was only 1 foot 8 inches thick, and the buttresses, spaced about 5 feet apart from centre to centre, were also 1 foot 8 inches thick by 2 feet 4 inches deep at the base and 9 feet 2 inches at the top. The work was hurriedly constructed during continuous rains with any stones that came to hand, and with very bad lime. When the filling had attained a height of 29 feet the wall bulged a trifle, but no further movement was noticed, though the filling, when carried up to the top of the coping, was allowed some weeks to settle in the rain. Earth was then piled above the level of the coping to a height of between 3 and 4 feet, when the wall fell. The fall was preceded by a general dislocation of the masonry at the base, a bulging at about one-third of the height, and a slight movement of the top towards the bank. The lower portion of the wall fell outwards, the upper part dropped vertically (as in General Burgoyne's wall, Fig, 1), and a considerable number of the counterforts went forward with the slip and even maintained their vertical position.

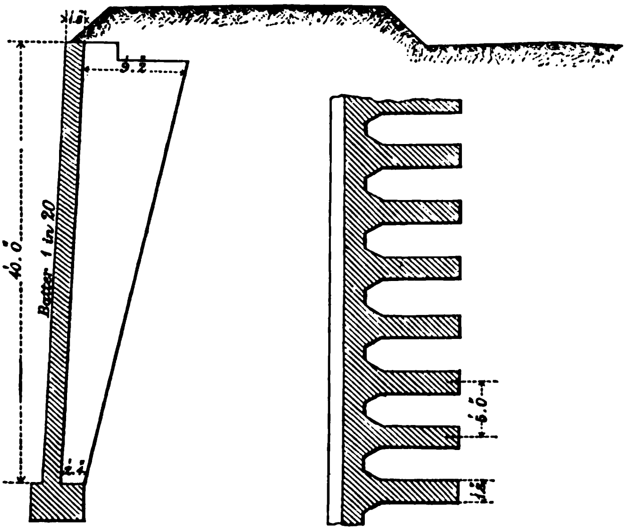


FIG. 3.

FIG. 4.

This failure arose from a flexure of the thin wall at the centre of pressure of the earthwork, and would not have occurred had the masonry been in cement instead of in weak unset lime. No direct data therefore are afforded for an exact estimate of the actual lateral thrust of the heavy wet filling on this lofty wall. Nevertheless, as the weight of the masonry was only 18,000 lbs. per lineal foot, and the centre of gravity of the same from the toe but 6 feet 6 inches, it follows that the wall, even if monolithic, would be overturned with the pressure of a fluid weighing 11 lbs. per cubic foot. How far the sodden earthwork between the counterforts contributed to the stability of the wall is open to question, but it could hardly account for the difference between the 11 lbs. or less stability and the 32 lbs. due, according to the ordinary theory, to the weight and slope of repose of the backing. If dirt were as good as masonry, General Burgoyne's wall with the battering back (Fig. 1) would have been more stable than the vertical wall (Fig. 2) in the ratio of the squares of their respective bases, or say as 2½ to 1, whereas these walls proved to be of equal stability, both falling with 17 feet of filling. Colonel Michon, by assuming dirt to be as good as masonry, and a wall 40 feet high and 1 foot 8 inches thick of unselected stones and unset mortar to be as good as a monolith, succeeds in reconciling the behaviour of his wall with the ordinary theory of the stability of earthwork; but in the Author's experience the conditions assumed are not approached in practice. The stability of this lofty wall battering only $\frac{1}{20}$ of the height on the face, and averaging hardly more than $\frac{1}{12}$ of the height in thickness is nevertheless one of the most remarkable and interesting facts connected with the subject of the present Paper.

To show how invariably an experimentalist is driven to the same conclusion as to the excess in the theoretical estimate of the pressure of earthwork, the "toy" experiments of Mr. Casimer Constable with little wooden bricks and peas for filling, may be usefully referred to.[1] The peas took a slope of 1·9 to 1, and weighed twice as much per cubic foot as the wooden retaining wall. By the Table the thickness of wall, which would just balance the lateral pressure would be $\cdot 35 \sqrt{2} = \cdot 49$ height. By experiment, a wall (Ex. 18) having a thickness of ·40 height moved over slightly, but took some amount of jarring to bring it down. Since the stability varies as the square of the thickness, the calculated wall would be 50 per cent. more stable than the actual wall, without considering the question of jarring. If the slope of the peas had been measured also, after jarring, it would probably have been found to be nearer 2·9 to 1 than 1·9 to 1, and the calculated required thickness would have been correspondingly increased.

The influence of even a slight amount of vibration is well illustrated by the difference between the coefficient of friction of stones on one another in motion and repose. Granite blocks, which will start on nothing flatter than 1·4 to 1, will continue in motion on an incline of 2·2 to 1, and, for similar reasons, earthwork will assume a flatter slope and exert a greater lateral pressure under vibration than when at rest. This fact has long received practical recognition from engineers; indeed, attention was called to it by Mr. Charles Hutton Gregory, C.M.G., Past-President, Inst. C.E., in a Paper on slips in earthwork, read before the Institution in 1844, when the President and others gave instances of slips in railway cuttings caused by vibration.[1]

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[1] *Vide* Trans. of the American Society of Civil Engineers, vol. iii., p. 67.

The general results of the preceding and other independent experiments on retaining walls tending to throw a doubt on the accuracy of Lieutenant Hope's measurement of the direct lateral thrust of ballast and sand on a board 1 foot square, the Author considered it advisable to repeat those experiments. Care was taken to eliminate all disturbing causes tending to vitiate the results. The pressure board was held by a string at its centre of pressure, and was perfectly free to move in every direction, which, of course, a retaining wall having a greater hold on the ground than stability to resist overturning has not. In every instance the filling was poured into the box and allowed to assume its natural slope towards the pressure board, and the latter was rotated and thumped to keep the ballast alive before the reaction was measured In order to avoid all chance of the bias which the knowledge what to expect might have given him, as it did Lieutenant Hope, the Author had the experiments made by others who were ignorant even of the object of them, whilst he himself purposely experimented with an apparatus the dimensions of which he did not know, and consequently could form no estimate of the weight which would be required in the scale.

With clean dry ballast having a natural slope of 1⅓ to 1, it will be remembered Lieutenant Hope obtained a lateral pressure on 1 square foot of 9 lbs. 7 oz. With well-washed wet ballast of the same kind the Author found the natural slope to be 1½ to 1, and he decided therefore to use the ballast wet, because, possessing greater fluidity, it would give more uniform results than dry ballast, and also impose greater lateral pressure. In a large number of independent experiments the results were uniformly as follows (Ex. 19): With 6 lbs. in the scale the board moved forward about ½ inch, but continued to retain the ballast; with 7 lbs. very slight movement occurred; with 8 lbs., no movement at all; and with

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. iii., p. 135.

10 lbs., under extreme vibration, the board moved forward about as much as it did with 6 lbs. without vibration. The general opinion of the different experimentalists was, that the fair value of the lateral pressure of this wet ballast was 7 lbs., because when that weight was in the scale-pan a slight jolt was sufficient to let the ballast down by the run to a slope of 1½ to 1. The board being 1 foot square, this of course is equivalent to the pressure of a fluid weighing 14 lbs. per cubic foot, instead of the 19 lbs. obtained by Lieutenant Hope, and the 26 lbs. indicated by theory.

With the same ballast unwashed and mixed with slightly loamy pit sand (Ex. 20) the natural slope was 1 to 1, without vibration, and 1¼ to 1 with a moderate amount of vibration. A weight of 3 lbs. was as effective in retaining this ballast as 6 lbs. in the former instance; 4 lbs. held it under a moderate amount of vibration, but 3½ lbs. failed to hold the board under very little. Practically speaking, the lateral thrust was about half that with the clean wet ballast, and considerably less than half that theoretically due to the slope of repose of the loamy ballast.

In harbour works both walls and backing are frequently completely immersed, and, so far as gravity is concerned, stone blocks and rubble become then transformed into coal. The Author therefore experimented (Ex. 21) with some coal having a peculiarly "greasy" surface, and offering the advantage of exceptional fluidity. With 3 lbs. the board moved forward about 1 inch, but no more until a slight jar was applied, when it fell; with 4 lbs. a moderate amount of vibration also generally caused failure; with 5 lbs. the board usually moved forward gradually without making a rush so long as a tolerably considerable amount of vibration was maintained. When a slip occurred the slope was invariably 1¾ to 1. The coal proved to be more sensitive to vibration than the wet ballast, and still more so than the unwashed ballast. A weight of 4 lbs. with the coal appeared to be equivalent to 7 lbs. with the washed and 3½ lbs. with the unwashed ballast. The weight of the coal being one-half that of the wet ballast, and the respective slopes of repose being 1¾ and 1½ to 1, the lateral thrusts would theoretically be as 16·8 : 28·7, which is practically the experimental result of 4 to 7.

The Author having occasion to design a solid pier 42 feet in height from the bottom of the harbour to the surface of the quay, where a soft bottom of great thickness and small consistency precluded the use of concrete block or other retaining wall, adopted an arrangement in which an iron grid of rolled joist, with a backing of large blocks of rubble, was substituted for a wall. It was necessary, therefore, to know the lateral thrust of large blocks of stone in such a structure, and mistrusting theoretical deductions, the Author made direct experiments on a model to a scale of 1 inch to the foot.

In this instance the individual stones were intended to be fairly uniform in size, and of lateral dimensions not less than $\frac{1}{20}$ of the height of the wall, so that the conditions differed considerably from those assumed in theoretical investigations. A number of billiard balls exactly superimposed in a tightly fitting box would exert no thrust though their slope of repose might be as flat as 3 to 1; and it is not quite clear how nearly or remotely large boulders in an iron cage approximate to that condition. The stones used in the experiment were waterworn pieces of schistose rock having a "greasy" surface and a slope of repose of 1½ to 1. This inclination was found by the Author to obtain in natural slopes of all heights from the pile of metalling by the roadside to the hills themselves. He ascended one slope of 1½ to 1, over 500 feet in height, and found the balance was so nearly maintained that a footstep at times would set many tons of stones in motion; and a few winters ago a couple of stones of the respective weights of 18 tons and 22 tons, descended this slope and acquired sufficient momentum to carry them across a road at the foot of the slope and on to the middle of the lawn in front of an adjoining shooting-lodge.

The conditions of the material were thus favourable, as in the instance of the coal, for obtaining uniform results and a maximum lateral thrust. In order to exclude all possible influence from side friction, the length of the box was made four times the height of the wall. As the result of ten experiments (Ex. 22), it was found that a weight in the scale corresponding to the pressure of a fluid weighing 10·2 lbs. per cubic foot sufficed to retain the rubble, though the face planking moved forward slightly as the last few shovelfuls were thrown against it. The weight of the stone filling was 98 lbs. per cubic foot, or practically the same as that of the wet ballast last referred to; so the 10·2 lbs., or say under slight vibration 11 lbs., in the present instance compares with the 14 lbs. of the previous instance, and the difference is a measure of the influence of large-sized, smooth-faced boulders as compared with ordinary ballast.

With coal of the same size (Ex. 23) the equivalent weight of fluid was 6 lbs. per cubic foot, which confirms the preceding result when regard is had to the respective weights and slopes of repose of the two materials. The experiments collectively proved that a wall, which according to the ordinary theory would be on the point of being overturned by the thrust of a bank of big boulders, would in fact have a factor of safety of nearly 2½ to 1.

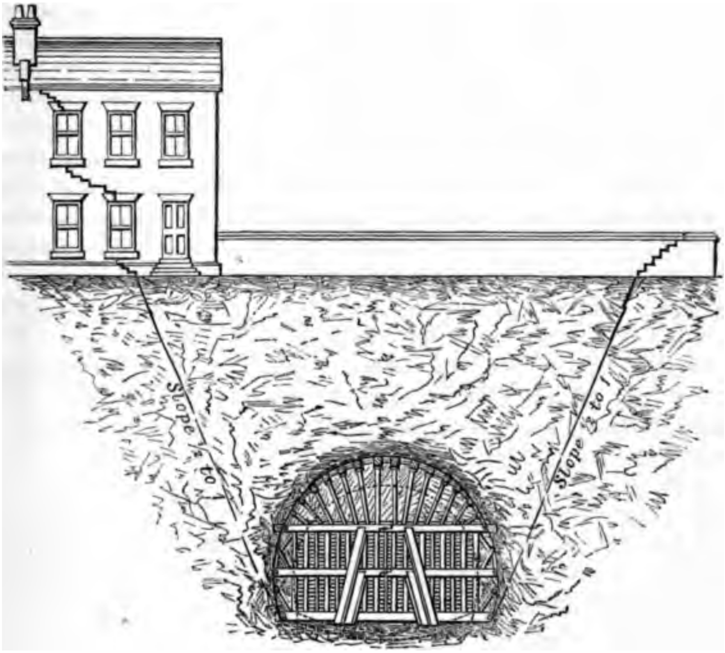
Having thus briefly reviewed some direct experiments on the actual lateral thrust of earthwork, the Author proposes to revert to the consideration of indirect experiments, dealing first with a few of those arising on the 34 miles of deep timbered trenches and other works of the "underground" railway.

In tunnelling very valuable evidence was afforded of the direction of the line of least resistance in a mass of earthwork. From the coming down of the crown bars, the changing of props, the crushing of timber, the compression of green brickwork and other causes, a settlement of from 6 to 8 inches usually occurred overhead, with a general draw of the ground towards the working end of the tunnel and the formation of fissures, attaining a maximum size where the line of least resistance cut the surface. Even when the settlement was slight, fissures were invariably observed in advance of the working end, and in continuous lines running parallel with the tunnel. The slope of these fissures was so uniformly at the angle of ½ to 1, measuring from the bottom of the excavation (Ex. 24, Fig. 5), that the resident engineer professed to be able to foretell with certainty where a building or fence wall, standing over the tunnel, would crack most. Assuming this ½ to 1 to represent Coulomb's line of least resistance, then the corresponding natural slope of repose of the material would appear to be 1⅓ to 1, which is considerably steeper than what it was in fact.

There is nevertheless a closer accord than usual between theory and fact in the instance of the several miles of fissures, which occurred during the construction of the tunnels of the Metropolitan railway. In other instances, such as the failure of ill-devised timbering, or the pushing forward of a retaining wall, by heavy clay pressing against its lower half, this accord was not always exhibited. In some cases no previous fissures have occurred, but a wedge of 1 to 1 has at once broken off and gone down with the timbering, whilst in others the fissure has appeared immediately at the back of the wall; indeed in one instance, for several consecutive weeks, the Author was able to pass a rod, 15 feet long, between the wall and the apparently unsupported vertical face of the ground behind it. The corresponding theoretical slope of repose would thus appear to be horizontal in one case and vertical in the other, which is sufficient evidence of the necessity of giving but a qualified assent to any theoretical deduction affecting the line of least resistance in earthwork.

A very fair notion of the relative intensity of lateral and vertical pressure in earthwork is often obtained in carrying out headings. The heading for the Campden Hill tunnel of the Metropolitan railway is a case in point (Ex. 25). The ground consisted of sand and ballast, heavily charged with water, overlying the clay through which the heading was driven, at a depth of 44 feet from the surface. After the heading had been completed some months, the clay became softened to the consistency of putty by the water which filtered through the numerous fissures, and the full weight of the ground took effect upon the settings. Both caps and side trees showed signs of severe stress throughout the entire length of the heading, and the occasional fractures in the roof and sides indicated that the timbers were proportionately of about the same strength, or rather weakness. The caps were of 14-inch square balks, with a clear span of 8 feet, and the sides of 10-inch square timber, with a clear span of 9 feet. Their respective

FIG. 5.



powers of resistance per square foot of poling-boards, supported, would therefore be as $\frac{14^3}{8^2} : \frac{10^3}{9^2} = 3\frac{1}{2} : 1$.

Now if one thing is settled by experience beyond all question, it is that the superficial beds of London Clay, sodden, as in the present case, with water, will not take a less slope of repose than 3 to 1. The average weight of the wet ground over the heading being about 1 cwt. per cubic foot, the theoretical lateral pressure on the side trees, at a mean depth of 48 feet from the surface, would be (see Table) $= 48 \times 0\cdot52 \times 1$ cwt. $= 25$ cwt. per square foot, and upon the caps $= 44 \times 1$ cwt. $= 44$ cwt. per square foot, or 1·76 time greater. But the side trees, as has been seen, had only $\frac{1}{3\cdot5}$ of the strength of the caps, so the irresistible conclusion is that the actual lateral pressure of the earthwork in this instance did not exceed one-half of that indicated by theory.[1]

It is readily shown that the full weight of the ground came upon the settings. Thus, assuming it to do so, the weight upon the caps would be $= 44$ cwt. $\times$ 8 feet clear span $\times$ 3·5 feet distance apart of the settings $= 1{,}232$ cwt., and taking the effective span at 9 feet, the breaking weight, upon the basis of Mr. Lyster's experiments on balks of similar size and quality, would be $\frac{2 \times 14^{3''} \times 2\cdot03 \text{ cwt.}}{9'} = 1{,}240$ cwt.; hence the occasional fractures of the balks are fully accounted for. Indeed, the heading would have entirely collapsed, in the course of time, had not the roof been supported by intermediate props practically quadrupling its strength.

In the early days of the construction of the Metropolitan railway, a definite type of timbering had not been arrived at, and some remarkably light systems were tried at times. The lightest the Author remembers was the timbering of the 14-feet wide gullet at Baker Street station (Ex. 26). Here the soil cut through was made up of about 8 feet of yellow clay and gravel, 7 feet of loamy sand, 7 feet of sharp sand and gravel, full of water, and 4 feet of London Clay at the bottom of the gullet. The timbering of the lower half consisted of 9-inch by 3-inch walings, 3 feet apart from centre to centre, in 12-feet lengths, with ¾-inch poling-boards at the back. With one-half the distributed breaking load, the deflection of this 3-inch deep beam at the span of 12 feet would be at least 4 inches, whilst the ultimate deflection would be measured by feet. As the walings did not bend nearly as much as 4 inches, it will be a liberal estimate to assume that the actual lateral pressure of the earthwork was equal to half the distributed breaking weight of the waling. Having reference to the quality of the timber, this may be estimated at $\frac{3^{2''} \times 9'' \times 2\cdot6 \text{ cwt.}}{12'\ 0''} = 17\cdot6$ cwt.; and since the area of the poling-boards supported by each waling was 36 square feet, it follows that the lateral pressure of the earthwork could not have exceeded 55 lbs. per square foot. But the depth of the bottom waling below the surface was 23 feet, or, neglecting the clay, and taking only the sharp sand and ballast charged with water, the depth would still be 20 feet, and the weight of fluid corresponding to the 55 lbs. per square foot pressure no more than 2·75 lbs. per cubic foot.

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[1] See also "Zur Theorie des Erddrucks," Weyrauch, Zeitschrift für Baukunde, vol. i., p. 129.

It will be remembered that the natural slope of the sand and ballast in Lieutenant Hope's retaining-wall experiments was about 1⅓ to 1, and that the actual and theoretical corresponding fluid pressures were respectively 10·3 lbs. and 23·6 lbs. per cubic foot. In the case of the gullet, the natural slope of the ballast and sand would similarly be not less than 1⅓ to 1, and yet the fluid pressure could not have exceeded 2·75 lbs. This one fact, therefore, is sufficient to prove that the universal assumption of the pressure of earthwork being analogous to that of fluid, and proportional to the depth, is one of convenience rather than truth. The explanation of the singularly small lateral thrust of the ballast in the present case is to be found in the fact that the ballast was lying between, and partially held back by, the two relatively tenacious layers of loamy sand and clay. As an extreme example of the same kind of action (Ex. 27), the Author may state that he once applied to a wooden box full of sand a pressure equivalent to a column of that material 1,400 feet high before the box burst. On the fluid hypothesis, the lateral pressure would have been 1,400 feet × 23·6 lbs., or about 15 tons per square foot; but of course a few lbs. would have burst the box, and the sand was retained by being jammed between the bottom and lid of the little deal box—the equivalents of the tenacious strata in the gullet.

In shafts the stress on the timbering is far less than in a continuous trench or heading, by reason of the frictional adhesion and tenacity of the adjoining earth. Thus (Ex. 28) at a depth of between 40 and 50 feet, 10-inch square timbers, 4 feet 6 inches apart, proved of ample strength to support the sides of a 12-feet square shaft, though the same sized timbers at the reduced distance of 3 feet 6 inches apart, failed, as has been seen, to support the *sides of a 9-feet* square heading.

After the experience of several rather troublesome slips, light timbering was abandoned, and a type which proved to be of ample strength to meet all the contingencies of heavy ground, vibration from road traffic, and the surcharge of lofty buildings, was adopted. In this type (Ex. 29) the 14-feet walings increased in scantling to 12 inches by 7 inches, were spaced 7 feet apart, and strutted at each end and at the centre. At one-half the breaking weight the supporting power of the walings would be about $\frac{7^2 \times 12 \times 3 \text{ cwt.} \times 112}{6\cdot5^2 \times 7} = 670$ lbs. per square foot, and as the depth of the excavation was in some instances as much as 36 feet, this would correspond to a fluid pressure of 18·6 lbs. per cubic foot. With ground weighing 112 lbs. per cubic foot, and a slope of repose of 1½ to 1, the theoretical lateral pressure would be 32 lbs. per cubic foot; and when it is remembered that this does not include any allowance for the surcharge due to contiguous buildings, and that the stress on the timber is taken at fully half the breaking weight, it is clear that the average actual lateral pressure of the earthwork must have been less than half that indicated by theory.

On the extensions of the Metropolitan railway, the same type of timbering was adopted, but the walings were generally 9 inches by 4 inches, and spaced 3 feet apart. The supporting power, upon the same basis as in the last instance, would be about 430 lbs. per square foot. In most cases this strength proved to be sufficient, but in a few instances the walings broke, or showed such signs of distress that additional support had to be given. This was the case in some of the deep trenches along the Thames Embankment, where heavy wet silt was traversed. Near Whitehall Stairs (Ex. 30) the trenches were 40 feet deep, so the elastic strength of the timbering was only adequate to the support of a fluid pressure of 10·6 lbs. per cubic foot, or probably but one-fourth of that theoretically due to the material; it is therefore no matter for surprise that the walings proved unequal to their work. The stability of the timbering in more moderate depths was, on the other hand, confirmatory of the general deductions drawn from previous examples as to the wide divergence between the actual and calculated thrust of earthwork.

Turning now from the consideration of the temporary works of timbering to the finished and permanent structures on the underground railway, a similar variation in strength will be found to obtain. The lightest retaining wall on the line is that at the Edgware Road station-yard (Ex. 31, Figs. 6 and 7). This wall is 23 feet in height from the top of the footing to the ground level, and has a maximum thickness of but 6 feet 3 inches at the base, out of which has to be deducted a panel 2 feet 6 inches deep. Calculating the moment of stability at the level of the footings and round a point 3 inches back from the face of the pier—which is a sufficient allowance for the crushing action on the brickwork—M = 4·4 feet, × 8,800 lbs. = 38,720 foot-pounds per lineal foot of wall. Dividing by $\frac{h^3}{6}$, then 19 lbs. per cubic foot is the weight of the fluid which would overturn this retaining wall. The ground supported is light dry sand, having a slope of repose of about 1⅓ to 1, and consequently exerting a theoretical lateral thrust equivalent to a 24-lb. fluid. There is practically no tenacity in the soil, as the Author remembers seeing demonstrated on one occasion when a horse and cart, approaching too near the top edge of the slope, broke it away and rolled together to the bottom of the 23-feet cutting. Although theoretically deficient in stability, and subject to heavy vibration from the two-minutes train service, the wall has stood perfectly without exhibiting the slightest movement. Upon the basis of the results of actual experiments, and having reference to the character of the soil and other conditions, the factor of safety would appear to be about 2 to 1.

FIG. 6.

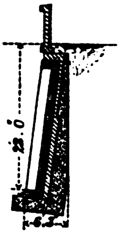
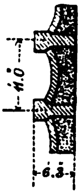


FIG. 7.



A far lower factor sufficed to secure the temporary stability of the dry areas at the station buildings previous to the erection of the arched roofs (Ex. 32). The arrangement at Sloane Square station is shown in Figs. 8 and 9. The joint stability of the front and back walls is the same as that of a solid rectangular wall having a thickness equal to $(2{\cdot}4 \times 2{\cdot}5 + 3{\cdot}8 \times 5{\cdot}2)^{\frac{1}{2}} = 5{\cdot}1$ feet, or say ⅙ of the height. A fluid pressure of about 9 lbs. per cubic

FIG. 8.

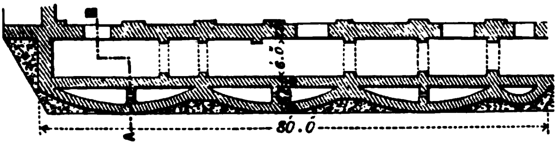
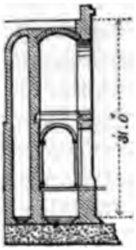


FIG. 9.



Section on line A B.

foot would upset such a wall, so the factor of safety, until the arched roof abutted against the dry areas, was only that due to the few 14-inch brick arches which tied the walls together with a certain amount of rigidity. This result would perhaps have surprised the Author more had he not previously investigated many cases of old timber wharves, in which the piles and planking had lost more than $\frac{3}{4}$ of their original strength from decay, and yet held on against a theoretically overpowering thrust of earthwork.

The relatively strongest wall on the Metropolitan railway system is at the St. John's Wood Road station (Ex. 33), and that has given considerable trouble. Though 8 feet 6 inches thick at the base, and backed up to a height of 16 feet only out of the total height of 21 feet 6 inches, and supported at the top by the thrust of the arched roof of the station, this wall moved over and forward to an extent which necessitated the immediate adoption of remedial measures.

The moment of stability per lineal foot $M = 73{,}000$ foot-pounds, consequently dividing by $\frac{16^3}{6}$ the fluid resistance is 107 lbs. per cubic foot, or allowing for the thrust of the arched roof of the station, considerably greater than that of a perfect fluid having the same density as the ground supported. It is not contended that such a pressure ever occurred upon the wall, although the ground is heavy yellow clay. The failure arose from causes which will be referred to more generally hereafter, and the case is only mentioned as a signal instance of the futility of hoping to reduce the engineering of retaining walls to the form of a mathematical equation.

It is a suggestive fact that, out of the 9 miles of retaining wall on the underground railway, the exceptionally weak wall should show no movement either during or after construction, whilst the exceptionally strong wall, though having six times the stability of the former, should fail. If an engineer has not had some failures with retaining walls, it is merely evidence that his practice has not been sufficiently extensive; for the attempt to guard against every contingency in all instances would lead to ruinous and unjustifiable extravagance, and be indeed as ridiculous a proceeding as the making every soft clay cutting at a slope of 10 to 1, because in a few places such cuttings happen to slip down to that slope.

In two instances comparatively heavy retaining walls have failed on the Metropolitan railway. During the construction of the line, the wall on the west side of the Farringdon Street station, (Ex. 34), failed bodily by slipping out at the toe and falling backwards on to the slope of the earthwork (Fig. 10). This wall (Figs. 11 and 12) was 29 feet 3 inches high above the footings, and 8 feet 6 inches thick. The ground consisted of about 17 feet of made ground, 3 feet of loamy gravel, and 9 feet of clay. At a distance of 15 feet from the back of the wall, and at a depth of 15 feet from the surface of the road, was the Fleet Sewer—a badly constructed and much broken brick barrel, 10 feet 6 inches diameter and 3 rings thick. It was believed that the leakage from the sewer induced the failure of the wall, but in reconstruction both wall and sewer were strengthened. The latter was made 4 rings thick in

FIG. 10.

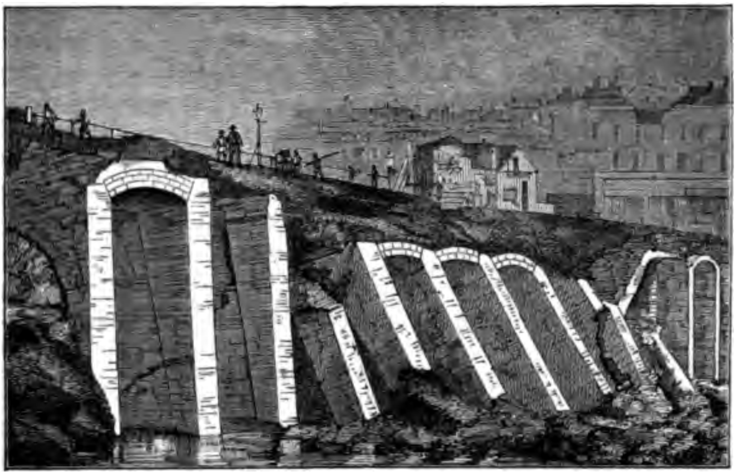


FIG. 11.

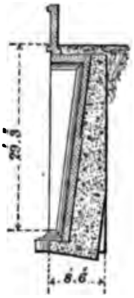


FIG. 12.

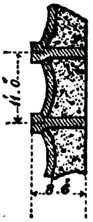


FIG. 13.

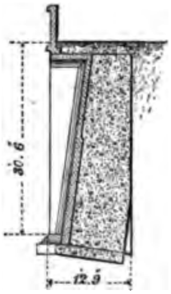
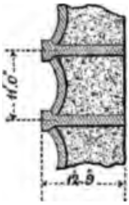


FIG. 14.



cement, and the former (Ex. 35) was increased in thickness to 12 feet 9 inches (Figs. 13 and 14). Originally the stability was equal to the resistance of a fluid pressure of 24 lbs. per cubic foot, and, as reconstructed, to 54 lbs.

On the opposite side of the same station-yard the ground was retained by a line of vaults (Ex. 36, Figs. 15 and 16), 29 feet high above the footings, and 17 feet deep—or double the original thickness of the wall last referred to. Although the resistance to overturning was greater in the proportion of 62 lbs. to 24 lbs. per cubic foot, the vaults some years after construction came over 15 inches at the top, and slid forward considerably more. The movement when once fairly commenced was rapid and alarming, as a mass of densely inhabited houses was within 20 feet of the back of the vaults. Steps were promptly taken to strengthen the work, by building intermediate piers and doubling the thickness at the back (Ex. 37, Fig. 17). This arrested the movement for a few months, when the vaults, whose stability had been thus increased to 93 lbs. per cubic foot, again began to go over and slide forward. It was clear that mere weight would not ensure stability, so 3-feet square brick struts were carried at intervals from the toe of the piers across and under the railway to the retaining wall of the low-level line traversing the station-yard at a distance of about 34 feet from, and 8 feet below, the level of the footings of the vaults.

Fig. 15.

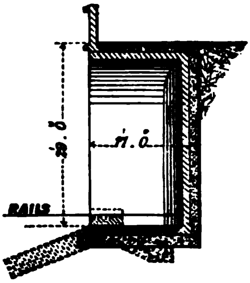


Fig. 16.

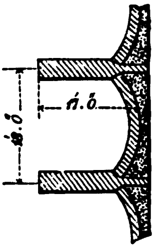
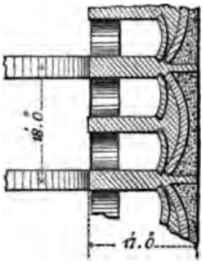


Fig. 17.

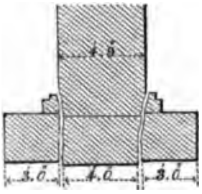


The soil in the preceding instance consisted of about 12 feet of made ground overlying the clay, and, as in the former case, a sewer was to be found rather close to the back of the work. Westward of the vaults, the clay encountered in the construction of the line was hard blue clay, requiring the use of a pick, and portions of the temporary cuttings in the station-yard, on the site where the vaults were subsequently built, stood fairly for many months at a slope of 1½ to 1. At one point, however, troublesome slips occurred, and even a 2 to 1 slope had to be piled at the toe to prevent forward movement. It was at this point that the vaults were subsequently found to be most dislocated.

In neither of the above cases was failure due to a deficient moment of stability in the wall, and therefore the fact of their failure does not in any way conflict with the results of the experiments previously set forth. In each case water at the back of the wall was as usual the active agent of mischief—not in thrusting the wall forward by hydrostatic pressure, but in softening the clay and affording a lubricant, so that the resistance was reduced to a sufficient extent to enable the otherwise innocuous lateral pressure of the earthwork to tilt and thrust forward the walls.

A costly, but conclusive, experience of this softening action was obtained in the instance of the central pier to the double covered way on the District railway near Gloucester Road station (Ex. 38). The weight per lineal foot was 21 tons per foot run of pier, and the 4-feet 9 inches was spread out by footings and concrete to a base of 10 feet: hence the pressure on the ground was 2·1 tons per square foot. In a similar construction near Aldersgate the load was 25 tons, and the width of base 8 feet 3 inches, giving the increased load of 2·9 tons upon the foundations. At the Smithfield market the Author did not hesitate to place a column carrying 435 tons upon a 12-feet-square base, which is equivalent to a load of 3 tons per square foot; and in the Euston Road, the side wall of the covered way has a load of 15 tons per lineal foot on a 4-feet-wide base, which is at the rate of 3¾ tons per square foot. In all instances the foundation was clay, of apparently equal solidity, and in every instance but the first no settlement at all occurred. For some years no settlement was observable in that case either, but ultimately, after an accidental flooding of the line, and permanent accumulation of water near the foundations, owing to the line being below the limits of natural drainage, and the pumping being neglected, cracks were observed in the arches, and on examination the concrete and footings of the central pier were found to be fractured as shown in Fig. 18. The load of 21 tons per lineal foot was thus imposed upon a base only 4 feet wide, and the softened clay proved unable to sustain the pressure of upwards of 5 tons per square foot. Considerable difficulty was experienced in checking the movement when once established. The centre pier was

Fig. 18.



underpinned with brickwork in cement, but the footings, though of exceptional strength, were again sheared off, and it was found necessary to use 6-inch York landings.

This failure shows the advisability of making concrete foundations of sufficient transverse strength to distribute the weight uniformly over the ground. As the result of experiment, the Author is of opinion that the ultimate tensile resistance in a beam of good cement or lias lime concrete, is about 100 lbs. per square inch, and in a beam of good brickwork in cement as much sometimes as 350 lbs. per square inch.[1] Taking the former value (Ex. 39), a 12-inch thick concrete foundation, projecting 12 inches from the face of a wall, would break with a distributed load $= \frac{12^3 \times 100}{6 \times 6} =$ 4,800 lbs.; or say 2 tons per square foot. With a pressure upon the foundation of, say, 3 tons per square foot, and a factor of safety of 2, the thickness of a concrete foundation would therefore be $\sqrt{\frac{3 \text{ tons} \times 2}{2 \text{ tons}}} = 1 \cdot 73$ time the amount of its projection beyond the face of the pier or wall, and the Author would not advise a less thickness being used when the foundation rests on plastic clay.

Water naturally gravitates to the foundation of a retaining wall, and a softening occurs. Owing to the lateral thrust of the earthwork, the pressure on the foundations is not uniform, and instead of settling uniformly, the outer edge descends fastest and the top of the wall is thrown outwards. The same softening reduces the clay to a condition in which it is easily ploughed up by the advancing wall, and the water acts as an admirable lubricant in diminishing the friction between the bottom of the wall and the clay on which it rests. These elements are exceedingly variable in their nature, and it is practically impossible to foretell the extent of their influence in each individual case.

In tunnelling, clay may be the best or the worst of materials —almost self-supporting, or pressing with irresistible force on the timbers and brickwork. It may be taken for granted that in good ground bad work will occasionally creep into tunnelling, however close the inspection. How good a material clay can be was enforced upon the Author's attention once in renewing a short length of defective tunnel lining, when on cutting down the work it was found that for some 50 feet the side wall, instead of being 2 feet 6 inches thick as intended, consisted merely of a skin of brickwork 9 inches thick on the face, with a number of dry bats thrown in loosely behind this thin face wall to fill up the space excavated. This tunnel (Ex. 40) was loaded with a weight of 46 feet of clay over the crown, but no measureable settlement had taken place ten years after completion, and it was rather by sounding the side wall, than by the observance of cracks, that a suspicion was raised as to its solidity. If the full weight of the ground had come upon the tunnel as it did upon the heading (Ex. 25), the pressure upon the side wall would have been 45 tons per lineal foot, or practically double the strength of the 9-inch work as determined by experiment.

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[1] *Vide* "The Strength of Brickwork." By B. Baker. "Engineering," vol. xiv.

Of course the clay in this case was hard blue clay, which had not been affected by the action of air and moisture. As explained by the Rev. J. C. Clutterbuck many years ago, the superficial layers of London Clay are yellow, because the protoxide of iron is changed into a peroxide by the action of air and moisture in the disintegrated mass, and it is the yellow clay, therefore, which is the dread of the engineer. As good an example as any of the difference between the two materials was afforded forty years ago, in the well-known slip which occurred in the 75-feet-deep cutting at New Cross, when nearly 100,000 tons of yellow clay slipped forward on the hard smooth surface of the shale—like underlying blue clay, and buried the entire line for a length of more than a hundred yards to a depth of 12 feet.[1]

Owing to a misunderstanding, a section of concrete wall designed by the Author to form one side of a running shed, and to retain the earthwork in a 13-feet cutting through light-made ground, was adopted also in a similar case, but where the ground was heavy wet clay, and the cutting 30 feet deep (Ex. 41). A wall 13 feet in height from formation to coping, and only 3 feet 3 inches thick at the base, had thus to sustain a surcharge of 17 feet. As the slope of repose was at least 1½ to 1, the lateral thrust was theoretically equivalent to a fluid pressure of about 70 lbs. per cubic foot, whereas a pressure of less than one-third that intensity would have overturned the wall. The latter nevertheless held up the ground fairly for some months, though the nature of the soil was such that it ultimately became necessary to add strong counterforts to the wall, and to reduce the slope of the cuttings generally to 2 : 1.

On the Thames Embankment heavy clay filling was in places cut through by the District railway, and in several instances the light side walls of the covered way were thrust over a few inches at the top before the girders were bedded (Ex. 42). The side walls were 18 feet in height from the invert to the ground level, and 5 feet 6 inches thick, with panels 5 feet 6 inches wide, by about 2 feet 9 inches deep, and piers 2 feet 6 inches wide. A fluid pressure of 16 lbs. would overcome the stability of these walls, but, though subject to the pressure of the heavy clay filling, none of them failed. The existence of an undue pressure was, however, manifested by the thrusting forward of the green brickwork during the few weeks that the walls were left unsupported by the girders.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. iii., p. 139.

The retaining walls, at the approach to Euston station, afford a good illustration of the impossibility of making any reasonable approximate estimate of the possible lateral thrust of yellow clay, or of stating positively that no movement will ever occur. These walls, soon after construction, were forced out in an irregular way at the top, bottom, or middle, but on pulling them down, the clay behind appeared to be free from fissures and to stand vertical. Cast-iron struts were subsequently put in between the opposite retaining walls; and although General Burgoyne, who had given much attention to the subject of revetments, prophesied at the time that they would be removed in a few years "when the ground had become consolidated," the struts still remain, and the walls still give signs of severe and increasing stress.

It is not only London Clay that proves so embarrassing to engineers. In a recent Paper[1] particular attention was called to the treacherous nature of some boulder clay which, "although so tough and tenacious as to give the utmost difficulty in excavation, after a short exposure became soft and pasty in the winter, often jolting down into a slurry." Examples were given of formidable slips in this material, in contrast with which the Author would point to the comparatively slow wasting of the huge boulder clay cliffs near the mouth of the Tyne, a matter which he had occasion to investigate very closely in connection with the Duke of Northumberland's lands in that district. From a comparison of surveys extending over a period of one hundred and fifty years, it appeared that the wasting of the cliff was very slow, and due solely to the wash of the waves at its base. At no time was the slope of repose of this 105-feet-high cliff more than 1 to 1, and in places it stood for years at an average slope of less than ¾ to 1. With his experience of North London Clay, the Author was startled to find people contentedly living in houses partially overhanging the brow of this steep and ragged cliff, but the stability of the clay was so great, and the wasting so uniform, that the fact of the outhouses being at the bottom of the 100-feet slope, and the main building at the top, did not appear in any way to disturb the equanimity of the householders.

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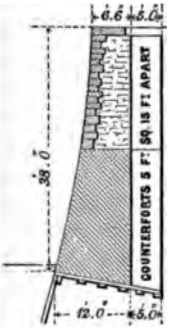
[1] *Vide* "Earthwork Slips," Minutes of Proceedings Inst. C.E., vol. lxii., p. 280 *et seq.*

The failures of dock walls, though numerous and instructive, afford no direct evidence as to The Actual Lateral Pressure of Earthwork, because in practically every instance the failure is traceable to defective foundations. The Author cannot recall any case in which a dock or quay wall founded on rock has overturned or moved forward, though on other foundations a movement to a greater or lesser extent is so much the rule that Voisin Bey, the distinguished engineer-in-chief of the Suez Canal, once stated to the Author that he could name no exception to it, since he had failed to find any long line of quay wall, which on close inspection proved to be perfectly straight in line and free from indications of movement. A brief examination of some instances of the failures of dock walls will show how powerfully unknown practical elements affect theoretical deductions in such cases.

A well-known and often cited case is that of the original Southampton dock wall, constructed now some forty years ago (Ex. 43, Fig. 19). This wall, 38 feet in height from the foundation to the coping, was built on a platform of 6-inch planks, resting on a sandy and loamy bottom. Before the water had been let into the dock, or the backing carried to the full height, the wall moved forward in some places as much as 3 feet, but came over hardly anything at the top. When the water was let in to the dock, the filling behind becoming saturated, the pressure on a receding tide was exaggerated, and to secure stability it was found necessary to discontinue the filling at some distance below the full height of the wall, and to substitute a timber platform.

FIG. 19.

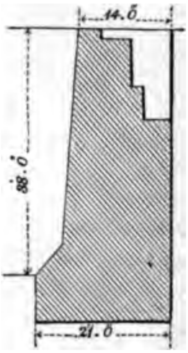


The thickness of this wall at the base is 32 per cent. of the height between the buttresses, 45 per cent. at the buttresses, and a rectangular wall containing the same quantity of material would have a thickness equal to 26 per cent. of the height. Though the base is wide, the weight is light as compared with most other dock walls, and the tendency to slide forward is therefore greater. If founded on a rock bottom, a fluid pressure of about 40 lbs. per cubic foot would have been required to overturn the wall, but of course a fraction of this pressure would suffice to make it move forward on the actual bottom.

The conclusion drawn by Mr. Giles, M. Inst. C.E., the engineer of the docks, from this and other failures is, that the quality of a dock wall is of little consequence compared with the quantity, and that it ought to be sufficiently strong not only to hold any amount of any kind of backing put against it, but to carry a head of water equal to its height if it were left dry on the other side.[1]

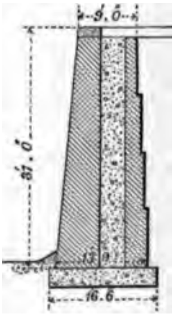
These principles have been adhered to in the recent extension of the Southampton docks (Ex. 44, Fig. 20). Here the wall is founded on a mass of concrete 21 feet wide; the effective thickness at base is about 45 per cent., and the mean thickness 41 per cent. of the height. A fluid pressure of from 60 to 70 lbs. would be required to overturn this wall if on a hard foundation, and probably as much to make it move forward, unless the bottom were of clay or of other unfavourable material. Mr. Giles has found even a heavier wall slide, when founded on a thin layer of gravel overlying clay. In the earlier wall, if the coefficient of friction of the base on the ground were less than $\frac{2}{3}$, the wall would slide rather than overturn; but in the later wall, without buttresses, any coefficient exceeding $\frac{1}{2}$ would be sufficient to prevent sliding.

FIG. 20.



For comparison with the above, the section of the east quay wall of the Whitehaven dock may be next referred to (Ex. 45, Fig. 21). Having the same height as the Southampton dock wall, the thickness at the base is but 37 per cent. of the height, the mean thickness 31 per cent., and the concrete foundation 16 feet 6 inches, instead of 21 feet wide. This wall has stood perfectly, though it would fail to resist the head of water mentioned by Mr. Giles, but would be overturned by a fluid weighing from 45 to 50 lbs. per cubic foot. During construction, weep holes were, however, left in the walls to relieve them of hydrostatic pressure.

FIG. 21.



Another dock wall, of the same height as the preceding ones, is that of the Avonmouth dock (Ex. 46, Fig. 22). In this instance the thickness is 42 per cent. of the height, and the concrete base 22 feet 6 inches wide, dimensions which, with a good foundation, would enable the wall to stand a full hydrostatic pressure at the back. Owing to the treacherous nature of the bottom, a long length of this wall nevertheless slipped forward at one point as much as 12 feet 6 inches, and sunk 4 feet 6 inches without the batter being affected, whilst at another point, where there was no forward movement, the wall came over about 1 foot 8 inches. Where the failure occurred, the foundation rested on apparently stiff blue clay, but in subsequent portions the concrete was carried down through the clay to the sand.[1] On the east side of the dock, though the walls were founded at an average depth of no less than 9 feet below the bottom of the dock, they still moved forward in the mass some 15 feet 6 inches, and sunk 7 feet 6 inches. The filling was carefully punned in layers, with material which seems to have stood fairly at a slope of 1½ or 2 to 1, so that the wall theoretically possessed an excess of strength, and yet, owing to the existence of conditions which it was impossible for the engineer to foresee, failures occurred as described.

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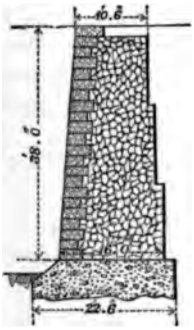
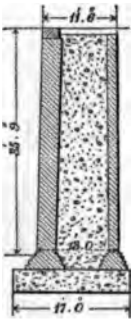
[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lv., p. 52.

Fig. 22.



A somewhat similar case of sliding forward occurred at the New South dock, West India Docks (Ex. 47, Fig. 23). The wall is 35 feet 9 inches high from the top of the footings to the coping, and 13 feet, or 36 per cent. of the height, thick at the base. The concrete foundation is 17 feet wide, and 6 feet deep below the bottom of the dock, and the fluid pressure required for overturning would be about 45 lbs. per cubic foot. A coefficient of friction of less than ½ would be sufficient to guard against sliding under this pressure, but owing to the existence of a thin seam of soft greasy silt between the hard strata of blue clay upon which the foundations rested, several portions of the wall slid forward. The original ground level was about 15 feet below the top of the dock wall, and the excavation stood fairly at a slope of 1 to 1. Favourable material for backing did not appear to be available.

Fig. 23.



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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lv., p. 15.

The fact that the stability of a dock wall depends far more upon the foundation than upon the thickness or mass of the wall itself, is well illustrated by the quay wall at Carlingford (Ex. 48, Fig. 24). With a height of no less than 47 feet 6 inches, the thickness of wall and width of foundation at the base are each but 15 feet, or less than 32 per cent. of the height, and the mean thickness is but 24 per cent. A lateral pressure of half that due to a hydrostatic pressure would probably suffice to overturn this structure.

In contrast with the preceding wall may be cited that of the dock basin at Marseilles (Ex. 49, Fig. 25). In both instances the foundation was good, and the wall rested immediately upon it without the interposition of any broad mass of concrete; but the French engineer, though the wall was but 32 feet high, made the thickness at the base no less than 16 feet 9 inches, or 52 per cent. of the height—an unusually large proportion, which he was led to adopt in consequence of the stratification of the ground inclining towards the wall.

Fig. 24.

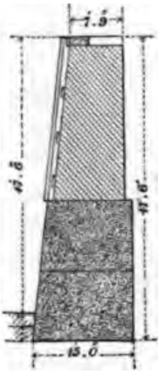


Fig. 25.

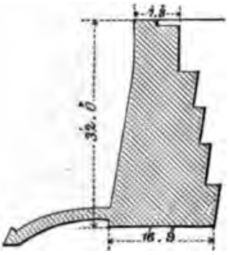


Fig. 26.

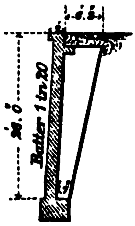
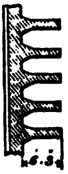


Fig. 27.



Perhaps one of the boldest and most successful examples of a lightly-proportioned wharf wall is that built by Colonel Michon in 1857 on the Moselle at Toul (Ex. 50, Figs. 26 and 27). With a height of 26 feet, and a batter of 1 in 20, the thickness of the wall through the counterforts is but 3 feet 7 inches at the base, and though the filling is ordinary material, having a slope of repose of 1½ to 1, and the floods rise within 6 feet of the top of the coping, no movement whatever has occurred since the wall was built.

As striking a contrast as could be wished to the above light construction is found in Sir John Macneill's quay wall at Grangemouth harbour (Ex. 51, Fig. 28). Both walls are of about the same height, but whilst the mean thickness of the first is only 3·7 feet, or $\frac{1}{7}$ of the height, that of the second, inclusive of the mass of concrete backing, is no less than 23 feet, or, say, $\frac{6}{7}$ of the height.

One of the most troublesome cases of dock-wall failures was that at the Belfast harbour[1] (Ex. 52, Fig. 29). This wall was founded upon round larch piles 15 feet long, 10 inches in diameter at the top, and 4 feet 6 inches apart from centre to centre. Symptoms of settlement became apparent soon after the filling was commenced, and some remedial measures were attempted. The ground, however, was hopelessly bad, the slope of repose ranging from 3 to 1 to 6 to 1, and the backing material being equally bad, the light piling was inadequate to resist the thrust. Two years after erection a length of about 70 lineal yards of wall was overturned and carried forward into the middle of the dock entrance, the piles being sheared off about 6 feet below the bottom of the wall. The height from the top of the pile to the coping is 31 feet 6 inches, and the thickness at the base 16 feet, or half the height. On good ground, therefore, the wall would have had an ample margin for stability.

FIG. 28.

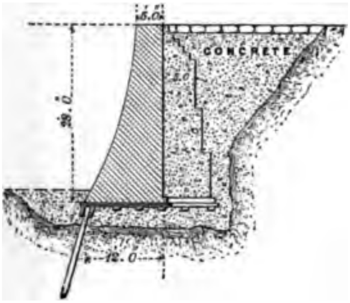


FIG. 29.

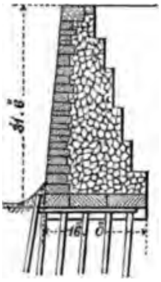
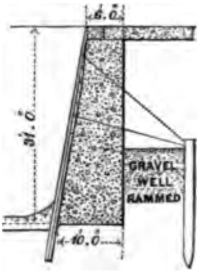


FIG. 30.



A somewhat similar failure occurred in the instance of the original side walls of the lock chamber of the Victoria docks[2] (Ex. 53, Fig. 30). These docks were built at a time when little confidence was placed in concrete as a durable material for dock work, and consequently the walls were faced with cast-iron piling and plates, as in previous instances at Blackwall and elsewhere. The foundations were on a layer of gravel overlying the clay, but the face-piling had little hold in the gravel, and the base of the wall itself was only some 30 per cent. of the height, hence, when the water was let into the dock, the hydrostatic pressure at the back of the lock wall forced it bodily forward into the lock, ploughing up the puddle in front of it, and breaking tie-bolts and tie-piles as it advanced. In reconstruction a solid concrete wall 20 feet thick, and having nearly treble the stability, was carried through the gravel down to the clay.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lv., p. 31.

[2] *Ibid.*, vol. xviii., p. 462.

The wall of the Victoria Dock Extension Works, by Mr. A. M. Rendel, M. Inst. C.E. (Ex. 54, Fig. 31), has a thickness of about 50 per cent. of the height at the point where the 18-feet wide foundation meets what may be termed the body of the wall, and the wharf wall of Mr. Fowler's Millwall dock (Ex. 55, Fig. 32) has a maximum thickness of 13 feet 6 inches for a height of 28 feet from bottom of dock to coping, or practically the same ratio. Either of these walls would be capable of resisting the full hydrostatic pressure.

Fig. 31.

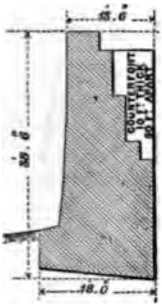


Fig. 32.

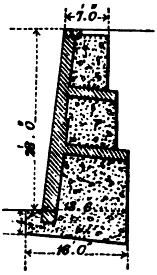
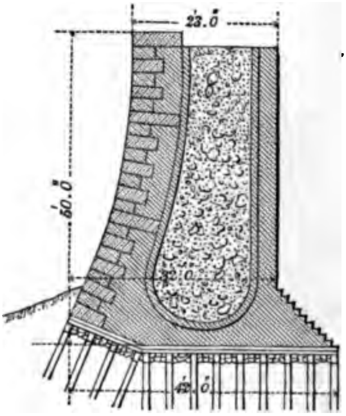


Fig. 33.



An early example of a successful wall on a very bad foundation is afforded by Sir John Rennie's Sheerness wall (Ex. 56, Fig. 33). The subsoil consisted of loose running silt for a depth of about 50 feet, covered with soft alluvial mud, and the depth at low water was at some points as much as 30 feet. A piled platform about 42 feet in width, with sheeting-piles on the river face, and 12-inch piles pitched from 3 to 4 feet apart over the whole area, and driven until a 15-cwt. monkey falling 25 feet did not move them more than ½ inch at a blow, was prepared, and upon this the wall, no less than 50 feet in extreme height and 32 feet in effective thickness at the base, was raised. In no case has any yielding or unequal settlement taken place, except in the instance of the basin wall, the cracks in which Sir John Rennie attributed to other causes than a failure in the foundation. Although the voids in the masonry were designedly filled in with grouted chalk and other light material, the Sheerness river wall has perhaps a greater moment of stability than any other wall in the world.

Another exceptionally heavy wall, more than half a century younger than the preceding, is that of the Chatham Dockyard Extension (Ex. 57, Fig. 34). The height from the bottom of the dock to the coping is 39 feet, and the foundations are carried down to the loam gravel or chalk at a depth of 4 feet 6 inches below the bottom of the dock. The thickness of the wall is 21 feet at the base, or, say, ½ of the extreme height. On a hard chalk bottom it would resist a fluid pressure of about 80 lbs. per cubic foot.

FIG. 34.

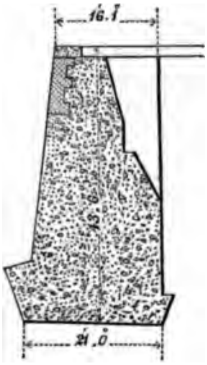


FIG. 35.

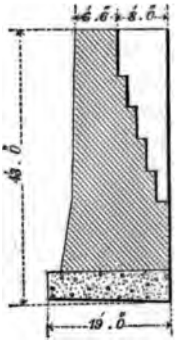
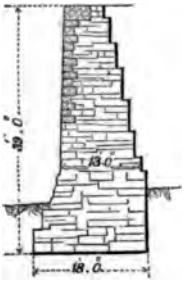


FIG. 36.



Two examples of Liverpool dock walls, namely, that at the Canada half-tide basin, and that at the Herculaneum docks, are given in Figs. 35 and 36. The former (Ex. 58) is 43 feet in extreme height, and 19 feet, or 44 per cent. wide at the base. The latter (Ex. 59) is 39 feet high, and 18 feet, or 46 per cent. wide at the footings, which rest on a marl bottom. A dock wall at Spezia (Ex. 60) of somewhat similar proportions, the height being 41 feet, and the width at the bottom of foundations 23 feet, or 56 per cent. of the height, is shown on Fig. 37.

Walls made of large concrete blocks, resting upon a mound of rubble, have been constructed in many of the Mediterranean ports, generally with success, but occasionally with failure, as at Smyrna, where, owing to the great settlement, six and seven tiers of blocks had to be superimposed instead of four, as intended, and the quay wall had after all to be supported by a slope of rock in front extending up to within 7 feet of mean sea-level, and seriously interfering with the use of the quays. The proportions arrived at by experience are a width of 9 metres at the top, and a thickness of not less than 2 metres for the rubble mound; a depth of 7 metres below the water-line, and a thickness of 4 metres for the concrete block wall resting on the mound; and a minimum thickness of 2·5 metres, and a height of 2·4 metres for the masonry wall coping the concrete blocks.

At Marseilles (Ex. 61, Fig. 38), the top of the rubble mound is only 6 metres below the water-line, so vessels occasionally bump; and the concrete block wall 3·4 metres, or 40 per cent. of the height, in thickness has proved rather less stable under the contingencies of working and the surcharge of buildings and goods than is considered desirable.

Fig. 37.

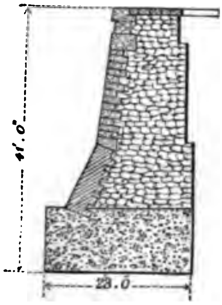


Fig. 38.

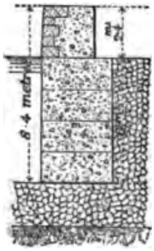
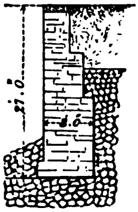


Fig. 39.



Examples are not wanting, however, of walls founded on rubble mounds where the thickness holds a smaller ratio to the height than the 42 per cent. considered necessary by the French engineers. Mr. Fowler has made concrete block walls in the Rosslare harbour (Ex. 62) 42 per cent. of the height on the sea face, and but 28 per cent. on the harbour side, but cross walls at 50-feet intervals considerably strengthen the work. The inner wharf wall of the Holyhead new harbour, again (Ex. 63, Fig. 39), is 27 feet high and 8 feet thick, a ratio of under 30 per cent., but though stable, the line of coping is somewhat wavy on plan. The original wall of the West pier at Whitehaven (Ex. 64, Fig. 40), is

42 feet 6 inches high, with a thickness of 8 feet 6 inches between the buttresses, which latter are 6 feet deep by about 4 feet wide and 15 feet apart; but the lightest of all, perhaps, is the dry masonry outer wall of the St. Katharine's breakwater, Jersey, (Ex. 65, Fig. 41), which is only 14 feet wide at the base for a total height of 50 feet, or a ratio of 28 per cent.

It must not be forgotten, of course, that the three latter walls have to support rubble hearting only, instead of sand and other material, having a much flatter slope of repose. Occasionally, as has been stated (Ex. 22), rubble will not stand at less than 1½ to 1; but at Holyhead and Alderney the slope of the rubble mound on the harbour side is only about 1¼ to 1. At Cherbourg it is 1 to 1, and at Leghorn the large concrete blocks are found to be stable at a slope of ¾ to 1. By a very little care in selection, the thrust of a rubble filling may be reduced to a fraction of that arising from bad material, and indeed in the ordinary run of fishing piers in the North of Scotland, however great the height, the face wall of the rubble-hearted pier consists simply of stones from 3 to 4 feet in depth, laid dry to a batter of about 1 in 5. The north-east pier at Seaham, again, has an inner wall 25 feet high, battering 1½ inch to the foot, and only 5 feet thick, and many similar examples are to be found at other points of the coast.

Fig. 40.

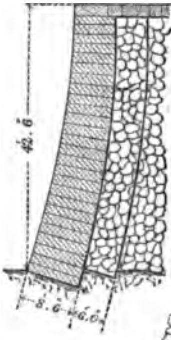
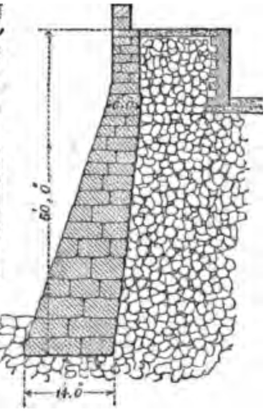


Fig. 41.



The most cursory examination of the cases of failure cited above will serve to justify the statement that the numerous dock-wall failures do not afford any direct evidence as to The Actual Lateral

Pressure of Earthwork. Thus, remembering that General Burgoyne's battering wall, only 17 per cent. of the height in thickness, supported the heavy sodden filling at its back, no calculation is required to show that the 32 and 45 per cent. Southampton dock counterforted wall, the 42 per cent. Avonmouth dock wall, the 36 per cent. West India dock wall, the 50 per cent. Belfast harbour wall, and the 30 per cent. Victoria dock wall, would all have stood perfectly had the foundation been rock, as in the instance of General Burgoyne's experimental walls, instead of the mud, clay, and silt which it actually was.

Not only the strength, but the type of cross-section, is singularly indicative of the small influence which theory and experiment have exercised upon the design of dock walls. If the early theorists and experimentalists were in accord upon one point, it was upon the immense advantages afforded by a counterforted wall. Lieutenant Hope was led by his experiments to conclude that if good counterforts were introduced, the merest skin of face wall would suffice for the portion between them, and theorists of course arrived at the same conclusion, from a comparison of the moments of stability of rectangular blocks of masonry edgewise and flatwise. Nevertheless, in only one of the preceding dock walls, and that one forty years old, are counterforts introduced. In practice it was found that counterforts frequently separated from the body of the wall, and they were consequently regarded as untrustworthy. It is open to question whether this conclusion does not require reconsideration in these days of cheap, strong, and easily-moulded Portland cement concrete. Nothing but blasting would separate the counterforts from a good concrete wall. The Author has used concrete in many varieties of structures, and as long back as fifteen years built a four-storey warehouse, walls and floors, entirely of concrete, without the introduction of any iron girders. He is bound to admit, however, that by far the boldest and most thorough adaptation of the material to multifarious uses met with by him was in the instance of some farm buildings in an out-of-the-way district in Co. Kerry, Ireland. The small tenant-farmer and his labourers—none of whom were receiving more than 11*s.* a week—without skilled assistance of any kind, had constructed dwelling-house, cattle-sheds, and hay-barn wholly of concrete. The cattle-shed was roofed with concrete arches of 15-feet span, 1 foot rise, and 4 inches thick, springing from octagonal concrete pillars 8 inches in diameter, spaced 15 feet apart from centre to centre. A layer of concrete constituted the paving, concrete slabs divided the stalls, the cattle fed and drank out of concrete troughs, the windows were glazed in concrete mullions, the gates hung on concrete posts, and the farmer seemed to regret somewhat that he had not adopted concrete doors and concrete five-bar gates.

Portland cement concrete being thus possessed of such great tenacity, there is no risk of counterforts separating from the body of a wall, but it by no means follows that there would be any advantage in using them in other than exceptional cases. In practice, as failures have shown, it is weight, with the consequent grip on the ground, rather than a high moment of stability, that is required in a dock wall. It may be asked, with reason, why a bad bottom should affect the thickness of a retaining wall, or, in other words, why the foundation should not first be made good, and then a wall of ordinary thickness be built upon it. The answer, of course, is that if weight is required to prevent sliding, it is just as economical to distribute the material over the general body of the wall as to confine it to the foundations. It follows, therefore, that under the stated conditions the adoption of a counterforted wall would lead to no economy in material, whilst it would involve additional labour in construction.

A dock wall is subject to far larger contingencies than an ordinary retaining wall, and the required strength will be included only within correspondingly large limits. Hydrostatic pressure alone may more than double or halve the factor of safety in a given wall. Thus, with a well-puddled dock bottom, the subsoil water in the ground at the back of the walls will frequently stand far below the level of the water in the dock, and the hydrostatic pressure may thus wholly neutralise the lateral thrust of the earth, or even reverse it, as in the case of the inner retaining walls on the Soonkêsala canal, some of which, though 35 feet in height, are only 2 feet thick at the top and 7 feet 6 inches at the base. On the other hand, with a porous subsoil at a lock entrance, the back of the walls may be subject, on a receding tide, to the full hydrostatic pressure due to the range of that tide plus the lateral pressure of the filling. Again, the water may stand at the same level on both sides of the wall, but may or may not get underneath it. If the wall is founded on rock or good clay, there is no more reason why the water should get under the wall than that it should creep through any stratum of a well-constructed masonry or puddle dam, and under those circumstances the presence of the water will increase the stability by diminishing the lateral thrust of the filling. With rubble filling, assuming the weight of the solid stone to be 155 lbs. per cubic foot, and the voids to be 35 per cent., the weight of the filling would be 100 lbs. per cubic foot in air, and 59 lbs. in water, and the lateral thrust will be that due to the latter weight.

If, however, as is perhaps more frequently the case, the wall is founded on a porous stratum, the full hydrostatic pressure will act on the base of the wall, and reduce its stability in practical cases by about one-half. Thus, the 30-ton concrete block walls on rubble mounds, at Marseilles and elsewhere, have the stability due to a weight of say 130 lbs. per cubic foot in the air and 66 lbs. per cubic foot in sea water; but the rubble filling at the back of the wall being similarly immersed, is also reduced in weight, and consequently thrust to a corresponding extent, so the factor of safety is unaffected.

In walls with offsets at the back, as in Figs. 25 and 36, and water on both sides, the stability will be much increased by the hydrostatic pressure on the top of the offsets, should the wall rest on an impermeable foundation. It is generally assumed, in theoretical investigations,[1] that the weight of earthwork superimposed vertically over the offsets should be included in the weight of the wall in estimating the moment of stability; but the Author has found no justification in practice for this assumption. He has invariably observed that when a retaining wall moves by settlement or otherwise, it drops away from the filling, and cavities are formed. A settlement of but $\frac{1}{32}$ of an inch, after the backing had become thoroughly consolidated, would suffice to relieve the offsets of all vertical pressure from the superimposed earth, and the latter cannot therefore be properly considered as contributing to the moment of stability.

A wall with deep offsets at the back is not a desirable form where the foundation is bad, and where consequently the pressure over the foundation should be as uniform as possible, so that a settlement may take the form of a uniform sinking, and not a tilting forward of the coping by reason of the toe sinking faster than the back of the wall. A panelled wall, such as that shown on Figs. 11 to 14, though not admissible in dockwork, is on bad ground far less liable to come over than a wall with offsets at the back, and with a consequent concentration of weight at the front, where the conditions of a lateral thrust especially require that it should not be.

The latter conditions also indicate the expediency of adopting raking piles, as in Fig. 33, rather than vertical piles, as in Fig. 29, where a piled foundation is unavoidable. Thus, taking an ordinary case of dock wall, in which the factor of safety, as regards overturning, is 3, and the ratio of weight of wall to the lateral pressure of earthwork required to overturn it is $1\frac{2}{3}$ to 1, it follows that if the foundation piles are driven at the rate of 1 to $3 \times 1\frac{2}{3} = 1 : 5$ there will be no transverse strain tending to break them off, as in the case illustrated by Fig 29, and no tendency to plough up the soft ground in front of the toe of the wall.

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[1] *Vide* "A Manual of Civil Engineering." By W. J. M. Rankine, p. 402.

If an engineer could tell by inspection the supporting power and frictional adhesion of every bit of soil laid bare, or see through 5 or 10 feet of earth into a "pot-hole," or layer of slimy silt, he might avoid many failures, and even hope to frame some useful equations for obtaining the required thickness of a dock wall. Taking things as they are, however, it is hardly worth while to use even a scale and compass in such work, for being in possession of all the information obtainable about the foundation and backing, an engineer may at once sketch as suitable a cross-section for the particular case as he could hope to arrive at after any amount of mathematical investigation. Something must be assumed in any event, and it is far more simple and direct to assume at once the thickness of the wall than to derive the latter from equations based upon a number of uncertain assumptions as to the bearing power of the foundations, the resistance to gliding, and other elements. This being so, it has often struck the Author that the numerous published tables giving the calculated required thicknesses of retaining walls to three places of decimals, stand really on exactly the same scientific basis, and have the same practical value, as the weather forecasts for the year in Old Moore's Almanack. In both cases a pretence is made of foretelling what experience has shown can often not be known until after the event. One well-known authority gives young engineers the choice of five hundred and forty-four different thicknesses for a simple vertical rectangular retaining wall, so that an unfortunate neophite might not unreasonably conclude that the task before him was not to decide whether, say, a 32-feet wall should be 20 feet thick, as in Example 60, or 9 feet, as in Example 62, but whether it should be 14 feet 6 inches or 14 feet $5\frac{1}{2}$ inches thick.

Although dock-wall failures do not afford any data as to The Actual Lateral Pressure of Earthwork, a knowledge of the latter will enable much valuable information to be deduced as to the bearing power of soil and other matters from such failures, and the data so obtained will be applicable to other structures beside retaining walls. Knowing the actual lateral thrust, the coefficient of friction of the base of a wall which has been pushed forward on the ground can be at once deduced, but if the theoretical as distinguished from the actual thrust were introduced into the equation, the result would be valueless.

The aim of the Author in the present Paper has been to set forth as briefly as possible what he knows regarding the actual lateral thrust of different kinds of soil, in the hope that other engineers will do the same, and that the information asked for by Professor Barlow more than half a century ago may be at last obtained. Although the acquirement of the missing data would probably lead to no modification in the general proportions of retaining structures, since these are based upon dearly-bought experience, it is none the less desirable that it should be obtained, for an engineer should be able to show why he believes that a given wall will stand or fall. To assume upon theoretical grounds a lateral thrust, which experiments prove to be excessive, and to compensate for this by giving no factor of safety to the wall, is not a scientific mode of procedure.

Experience has shown that a wall ¼ of the height in thickness, and battering 1 inch or 2 inches per foot on the face, possesses sufficient stability when the backing and foundation are both favourable. The Author, however, would not seek to justify this proportion by assuming the slope of repose to be about 1 to 1, when it is perhaps more nearly 1½ to 1, and a factor of safety to be unnecessary, but would rather say that experiment has shown the actual lateral thrust of good filling to be equivalent to that of a fluid weighing about 10 lbs. per cubic foot, and allowing for variations in the ground, vibration, and contingencies, a factor of safety of 2, the wall should be able to sustain at least 20 lbs. fluid pressure, which will be the case if ¼ of the height in thickness.

It has been similarly proved by experience that under no ordinary conditions of surcharge or heavy backing is it necessary to make a retaining wall on a solid foundation more than double the above, or ½ of the height in thickness. Within these limits the engineer must vary the strength in accordance with the conditions affecting the particular case. Outside these limits the structure ceases to be a retaining wall in the ordinary acceptation of the term. A 9-inch brick facing might secure the face of a friable chalk cutting which, if suffered to remain exposed to the action of the weather, would crumble down to a slope of 1 to 1, and a massive bridge pier, with an "ice-breaker" cutwater, might stand firm against an avalanche, but in neither case could the structure be fairly stated to be a retaining wall.

Hundreds of revetments have been built by Royal Engineer officers in accordance with General Fanshawe's rule of some fifty years ago, which was to make the thickness of a rectangular brick wall, retaining ordinary material, 24 per cent. of the height for a batter of $\frac{1}{5}$, 25 per cent. for $\frac{1}{6}$, 26 per cent. for $\frac{1}{8}$, 27 per cent. for $\frac{1}{10}$, 28 per cent. for $\frac{1}{12}$, 30 per cent. for $\frac{1}{24}$, and 32 per cent. for a vertical wall.

As a result of his own experience the Author makes the thickness of retaining walls in ground of an average character equal to $\frac{1}{3}$ of the height from the top of the footings, and if any material is taken out to form a face panel, three-fourths of it are put back in the form of a pilaster. The object of the panel, as of the $1\frac{1}{2}$ inch to the foot batter which he gives to the wall, is not to save material, for this involves loss of weight and grip on the ground, but to effect a better distribution of pressure on the foundation. It may be mentioned that the whole of the walls on the District railway were designed on this basis, and that there has not been a single instance of settlement, or of coming over or sliding forward.

The Author has in the present Paper analysed a few dozen experiments, and discussed as many more facts; but an engineer's experience is the outcome not of a few facts, but of the thousands of incidents which force themselves upon his attention in carrying out work, and it is this experience, acquired in the construction of works of a somewhat special character, which has convinced the Author that the laws governing the lateral pressure of earthwork are not at present satisfactorily formulated.

INDEX OF EXAMPLES AND FIGURES.

THEORETICAL LATERAL PRESSURE OF EARTHWORK.

Diagram for obtaining the equivalent fluid pressure and required thickness of retaining wall.

Table of fluid pressures and thicknesses of wall for different slopes of repose.

ACTUAL LATERAL PRESSURE OF EARTHWORK.

Example.		
1.	Wood-block wall and ballast backing . . .	Author.
2.	Slag " " slag " . . .	"
3.	Pressure-board experiments with sand . . .	Lieut. Hope, R.E.
4.	" " " ballast . .	"
5.	Angle of rupture in sand	"
6.	" " ballast	"
7.	Experimental brick wall, 10 feet high . . .	"
8.	" " 12 " 10 inches high	"
9.	" " 21 " 6 "	"
10.	Model revetment walls	Gen. Pasley, R.E.
11.	" "	Gen. Cunningham, R.E.
12.	" "	"
13.	Experimental stone wall, 20 feet high . . .	Gen. Burgoyne, R.E.
14.	" " " . . .	"
15.	" " " (Fig. 1)	"
16.	" " " (Fig. 2)	"
17.	" " 40 " (Figs. 3, 4)	Col. Michon.
18.	Model wood-block walls	C. Constable.
19.	Pressure-board experiments with wet ballast .	Author.
20.	" " loamy "	"
21.	" " coal . . .	"
22.	" " large rubble	"
23.	" " " coal .	"
24.	Angle of rupture of earthwork over tunnel (Fig. 5)	"
25.	Pressure of earth on timbering of heading at Campden Hill . .	"
26.	" " gulley at Baker Street	"
27.	" experimental box of sand	"
28.	" timbering of shafts . .	"
29.	" timbering of trenches, Metropolitan railway	"
30.	" timbering of trenches, Metropolitan District railway	"
31.	" retaining wall at Edgware Road . . .	Figs. 6, 7.
32.	" dry areas at Sloane Square	" 8, 9.

Example.		
33.	Retaining wall failure, St. John's Wood railway.	
34.	„ „ Farringdon Street.	Figs. 10, 11, 12.
35.	Reconstructed wall „	„ 13, 14.
36.	Retaining vaults, failure „	„ 15, 16.
37.	Reconstructed vaults „	Fig. 17.
38.	Pressure on foundations, Metropolitan District railway	„ 18.
39.	Strength of concrete and brick footings.	
40.	Pressure on side wall of tunnel.	
41.	Retaining wall failure from heavy surcharge.	
42.	Side wall to covered way, Metropolitan District railway.	
43.	Dock wall, Southampton docks	„ 19.
44.	„ „ „ extension	„ 20.
45.	„ Whitehaven „	„ 21.
46.	„ Avonmouth „	„ 22.
47.	„ West India „	„ 23.
48.	„ Carlingford harbour	„ 24.
49.	„ Marseilles docks	„ 25.
50.	Wharf wall, Toul on the Moselle	Figs. 26, 27.
51.	„ Grangemouth harbour	Fig. 28.
52.	Lock wall, Belfast harbour	„ 29.
53.	„ Victoria docks	„ 30.
54.	Dock wall „ „ extension	„ 31.
55.	„ Millwall „	„ 32.
56.	River wall, Sheerness „	„ 33.
57.	Dock wall, Chatham „	„ 34.
58.	„ Canada half-tide basin	„ 35.
59.	„ Herculaneum docks	„ 36.
60.	„ Spezia	„ 37.
61.	Quay wall of concrete blocks, Marseilles	„ 38.
62.	„ „ Rosslare.	
63.	„ of masonry with rubble backing, Holyhead	„ 39.
64.	„ „ „ Whitehaven	„ 40.
65.	„ „ „ St. Katharine's	„ 41.

Discussion.

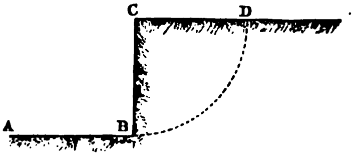
Mr. Bake

Mr. B. Baker desired to add, that his object in bringing forward the Paper was not so much to present certain facts for criticism as to induce others to give the results of their experience, and if every one helped a little he thought a very useful result would be attained.

Mr. Airy.

Mr. W. Airy said he had given considerable thought and attention to the subject of earthwork, and he considered the collection of examples in the Paper would make it an extremely useful one for purposes of reference. The subject of earthwork was a very difficult one to deal with, and he wished to point out briefly in what this difficulty consisted. A B C D (Fig. 42) might be taken to be the section of some ground having a small vertical cliff at B C. There would be a tendency for the ground to break away and come down along some such line as D B. The whole problem of the stability of the ground, both as affecting the slope of the earth and the pressure against a retaining wall, depended upon the accurate determination of the line D B. It was not an exceedingly difficult matter to determine this line, if the constants of cohesion, friction, and weight of the ground were known; and he had himself dealt with the problem in a Paper communicated to the Institution.[1] The mechanical conditions of equilibrium were very simple; the force tending to bring the earth down was the weight of it; the forces tending to keep it from coming down were the friction along the line D B and the cohesion of the ground along that line. All those forces acted according to well understood laws, and therefore if the constants of weight, cohesion, and friction of any particular ground were known, it was not difficult to find out the exact position of the line D B, and therefore the pressure on the retaining wall, or the shape of the

Fig. 42.



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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lv., p. 241.

Mr. Airy. slope. The question then arose, what was the real difficulty of constructing tables for practical use with regard to earthwork? Simply this, that the varieties of ground were infinite in number and very wide in range, and when that was the case it was quite idle to think of constructing tables for practical use. A man having a particular kind of earth to prescribe for would not be able to ascertain by inspection what the constants of that earth were, and therefore he would not know whereabouts in a table to look; he would have to determine the constants for himself; and if he had to do that he had to do the whole work, and the tables were of no use to him. He thought the Author had rather overlooked the enormous number of conditions of earth when he contrasted the small number of experiments upon earthwork with the large number of experiments made with timber. A piece of oak would give very nearly the same results for strength, elasticity, and so on, whether it was grown in Kent or in Yorkshire; and, therefore, when a few experiments had been made upon it, it was not necessary to repeat them over and over again. That was not the case with earthwork, because the conditions were so exceedingly variable. He exhibited a little rough machine he had used for testing earthwork and taking the cohesion of the ground. The block of wood might be taken to represent a block of raw clay taken out of a cutting. There was a common lever-balance, and a couple of movable cheeks were fitted into chases cut in the sides of the clay block; and the clay having been rammed in a box so that it could not move, weights were put in the scale until the head was torn off. After subtracting the weight of the piece that was torn off, and measuring the area of the cross-section that was broken, the constant of cohesion was determined. For the constant of friction he arranged a certain number of blocks of the same clay in a tray, and scraped them off smooth; then he had another block of clay with a smooth surface which he put on it, and then tilted the tray until the loose block slid; that gave the coefficient of friction. He should like to refer to the exceedingly wide range of tenacity shown by different kinds of clay. In one set of experiments with ordinary brick loam, that clay gave a coefficient of cohesion of 168 lbs. per square foot, and a coefficient of friction of 1·15. With some shaley clay out of a cutting in the Midlands, he had found a coefficient of tenacity of 800 lbs. per square foot, and a coefficient of friction of 0·36. That was a very wide range, but it was only a part of what was actually to be found in practice.

Mr.
Harc

Mr. L. F. Vernon-Harcourt wished to say a few words on the subject, as the Author had referred to two or three works with which he had been connected. The Author had pointed out, from the experiments he had recorded, that the pressure upon the back of a retaining wall was a good deal less than it was theoretically supposed to be—about one-half—but as he allowed a factor of safety of 2, it apparently came to very much the same thing. With regard to walls on a rubble mound, the Author remarked that the base was in many cases small. That, he thought, was owing to two causes; first, that with a rubble mound for a base there was no chance of sliding; and secondly, that in those cases there was a rubble filling behind, which he supposed was about as good a material for backing as could be got. The slope of the inner face of the rubble mound of the breakwater at Alderney harbour had been referred to as 1¼ to 1; but it ought to be remembered that in that case the materials used were very large blocks of stone, and therefore the slope would be naturally steeper than under more ordinary conditions. Reference had also been made in the Paper to St. Katharine's breakwater, Jersey, as an example of a wall built with a very small base. The Author took the whole of the height of that wall as the proper height; but it would be observed that the top of the wall had what used to be called a promenade along it, and therefore the whole of the filling did not apply to the entire height of the wall. The Author stated that the base was 28 per cent. of the height of the wall, but leaving out the promenade it would be 35 per cent. Of course i would be something intermediate, as there would only be th small piece of filling under the promenade to be taken into account additional, instead of what would be the filling at the back if it was filled up entirely to the top level. The Author had referred to the West India dock wall, and stated that several portions of it had come forward. That, however, was not quite the case. It was true that two portions of the south wall came forward—that two surfaces of clay at some little depth below the wall slid upon one another. Probably some seam of sand or silt was washed out by the water behind the wall from between two layers of clay, and in that way the two detached surfaces of clay were free to slide upon one another. He was quite certain of the exact position of the surfaces of rupture, because he saw the two surfaces of clay after the excavation was made for rebuilding the wall, and they were as smooth as glass. The remedy for that appeared to him to be very simple, and it was certainly successful in the case in point. The wall had failed, as the Author

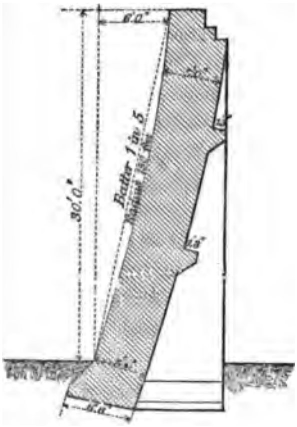
Mr. Vernon-Harcourt. had stated, not from any fault in the thickness or the weight, but simply owing to the sliding forward; and instead of adding any further weight to the wall, the foundations were carried down to a greater depth; but it only required 2 or 3 feet more in depth in the basin wall foundations that had to be executed afterwards under precisely similar conditions. That was quite sufficient to keep the wall in a perfect state of equilibrium without the least coming forward; and he should imagine that was decidedly better on the whole than adding to the weight of the wall. It appeared to him that practice was rather contrary to theory in giving too great a thickness to the top of the wall, and too small a thickness, comparatively speaking, to the bottom; and that it would be better to have a wall more of the shape of the Sheerness wall a good deal lessened at the top, rather than a wall like those generally adopted, which had more parallel faces with a little additional thickness from the batter. He thought it would be better to make a wall narrower at the top and widening out more towards the bottom, and to bring the foundations of the wall well down into the ground so as to prevent any chance of sliding. In the case of the West India dock wall, besides the badness of the backing, there was a large amount of water that seemed to percolate from the Millwall docks, which were filled with water while the wall was being built, the docks not having been puddled. It was clearly shown that that had a considerable effect, because the north wall, though it was built in exactly the same manner, and though the water of the Export dock was really nearer, stood perfectly, as there was not the same amount of water-pressure at the back, owing to the water being unable to penetrate through the silted-up bottom of the Export dock. He considered that the Institution was much indebted to the Author for collecting and comparing so many valuable facts, as, whilst descriptions of particular works were very useful, it was by taking a general survey, from time to time, of the existing state of knowledge, in any special branch, that definite progress in engineering science was most likely to be promoted.

Mr. Barry. Mr. J. WOLFE BARRY believed the statement was true, that the pressure against retaining walls did not approach to the theoretical thrust; at the same time he was of opinion that large retaining walls gave the engineer as much anxiety as any work he ever undertook. It should be remembered that, as a rule, the thrust which the walls had to bear came against them when the material of which they were composed was green, and unless contractors and others were very careful in strutting the new work, and allowing plenty of time for the material to set, there would be a condition of affairs in the early stages of the wall which would never arise after the materials were thoroughly consolidated. He wished to point out that it was for such reasons most engineers were now getting to realise the extreme desirability of using cement as much as possible. The early stages of engineering works were generally those in which the greatest risks were run, and if a slow-setting material were used, the strains would be exerted against it in its weakest condition, and disasters would occur such as would not happen at a later period. He agreed with the statement of the Author with regard to the failure of retaining walls. No doubt, in ninety-nine cases out of a hundred, the failure happened from bad foundations. The remedy in railway works was in many cases that shown in Fig. 17, which practically amounted to strutting the toe of the wall against the opposite wall, and so preventing it sliding forward. That was a very simple arrangement, and resembled in its effect the strutting of timber which was generally carried out as a temporary measure by a contractor when an invert was going to be put in. If the engineer thought that a continuous invert could be dispensed with, a half measure, which was often perfectly good, was to adopt some of these struts—which in fact were a discontinuous invert, as shown in Fig. 17. In railway walls he thought engineers were a little too apt not to use struts above the trains, it being considered in many cases rather *infra dig.* to strut a wall. He could not see why it should be so. The horizontal strains exerted against the retaining wall about 14 feet or 15 feet high above its base were small; the struts consequently involved a very small expense, but they prevented all possibility of movement, and they saved a large amount in the cost of the wall. Having had something to do with the Metropolitan District railway, he could thoroughly corroborate the statement of the Author, that the walls had stood remarkably well. As far as he knew, there was no sign of failure or incipient failure in any of them. There was, however, one little matter he had noticed: viz., that in many of the walls there was a small angular crack across the external angles of the piers. He did not know how the cracks had originated, but he thought they might be due to the action of frost: the corners getting saturated, the frost attacked the brickwork at the angles and broke them off. If so, it rather pointed out that in such walls it might be desirable to round the angles, or have angular bricks and avoid the sharp corners. Mr. Barry

Mr. W. B. Lewis said, the experience gained in the construction Mr. Lewi

Mr. Lewis. of the Underground railway was so large that the profession naturally looked for the opinions of some of those who were concerned in it; and they all felt grateful for the fulness and ability with which those opinions had been expressed in the Paper. He thought the Paper was open to this reflection: that whereas the Author in the earlier pages discredited the theoretical views that generally prevailed respecting retaining walls, in the latter part he stated that his practice had pretty well accorded with them. For instance, he gave the theoretical thickness for a retaining wall in ground that naturally stood at a slope of 1½ to 1 as 31 per cent. of the height; and in the last paragraph but one he said his habit had been to make his walls ⅓, or 33 per cent.; and in the Table with slopes from 1 to 1 to 4 to 1, which included all that engineers usually had to deal with, his theoretical thickness ran from 0·239 to 0·451, while in the concluding paragraphs of the Paper he stated that the engineer must work between the limits of ¼ the thickness and ½, which seemed to agree with the theoretical thickness. The general conclusion that engineers must work between ¼ and ½ was different from the practice in which Mr. Lewis had been trained, and he had therefore brought a diagram (Fig. 43) of a retaining wall constructed according to Mr. Brunel's rules. Of course Mr. Brunel, who had to carry out very great works, modified his rules to suit the circumstances; but the diagram represented his standard section of wall such as was constructed at Lord Hill's land in the early days of the Great Western railway, and at the Briton Ferry docks two years before his death. It would be seen that the dimensions and peculiarities of that wall differed very much from those given in the Paper. In the first place the wall had an average batter of 1 in 5, and at the top a batter of 1 in 10. Batter was a point on which Mr. Brunel always insisted, and Mr. Lewis was a little surprised that the Author seemed to treat it with so much indifference. He was evidently aware of its value, because in the early part of the Paper he mentioned a wall with a batter of 1 in 5, and a thickness of 1 foot, which he said was equivalent to a vertical wall of 1 foot 9 inches. Now anything that

FIG. 43.



Scale, 16 feet = 1 inch.

was equivalent to an increase of the original value of 73 per cent. Mr. Lewis. was well worthy of consideration. Mr. Brunel's custom was to curve the face of the wall. The radius was 150 feet in the case of a 30-feet wall, or five times the height. The thickness was $\frac{1}{5}$ to $\frac{1}{6}$ the height. The counterforts were 2 feet 6 inches thick, and placed 10 feet apart from centre to centre, but were omitted in good clay cuttings. In the case of docks sometimes there was a difficulty, in consequence of the necessity of having the top more upright, and at Briton Ferry docks the radius was reduced by nearly one-half. Mr. Brunel, too, was in the habit of building behind what he called sailing-courses, and the projections in Fig. 43 were 1 foot 3 inches. In the case of embankments the wall was supported by earth carefully punned against it and against the sailing courses, thereby adding considerably to the weight that had to be overturned when pressure came from behind. Then his rule for thickness was $\frac{1}{6}$, which was below the minimum given by the Author. There were a number of such walls at Paddington, Bath, Plymouth, Briton Ferry, 30 feet high and 5 feet thick, and generally of nearly the same thickness at the top as at the bottom. Another point Mr. Brunel was particular about was that the footings were made square to the batter, and when the ground was not good considerably larger footings were introduced. At Briton Ferry a 2-feet lining of concrete was employed at some places for watertightness. Concrete was not then in such general use as it was at present. Of course when exceptional ground was met with it was dealt with exceptionally. At a tunnel on the Wilts, Somerset, and Weymouth railway, some heavy ground had been found; the tunnel mouth was in a 60-feet cutting, a retaining wall 30 feet high was built, and the top was sloped back at $\frac{3}{4}$ to 1, with a 2-feet covering of masonry, and the wall was built precisely of the dimensions represented by Fig. 43; but as the ground was heavy, the batter, instead of being 1 in 5, was 1 in 4, and that was the only alteration. That wall was built in 1854, had never given any trouble, and was standing at the present moment. It seemed to him that Mr. Brunel, forty years ago, came nearer to the teaching of the experiments and of the reasoning in the Paper, than the Author had ventured to do in his own practice.

Mr. J. B. Redman observed that the Author had undoubtedly Mr. Redm filled a void in the literature of engineering; for, notwithstanding the great experience that most of the members of the Institution had of such catastrophes as those which had been referred to, it was only human-like that they had not been often recorded by

r. Redman. the designers of the works. Those who constituted what was now a select minority of the Institution would remember the partial failures of Mr. Robert Stephenson's retaining walls in the Euston cutting of what was then the London and Birmingham, and now the London and North-Western railway. Those partial failures were met by overhead horizontal girder struts supporting the walls, and it was rather curious that, notwithstanding all the experience that had been since gained, in a large number of instances, in metropolitan railways, the overhead girder had been, as it were, the natural sequence of what might be termed the unretaining wall. There was one circumstance which very much complicated the question of the direct lateral thrust of earthwork upon a retaining wall, and which rather curiously had not been mentioned by the Author. It was incidentally referred to in the latter part of the Paper, where the Author said French engineers, in designing a wall at Marseilles, made the width of the base 58 per cent. of the vertical height, in consequence of the dip of the strata being towards the wall. In a large number of cases of the failures of retaining walls in open cuttings near London, he thought it would be found that the failure was entirely on one side. Where the dip of the strata was towards the cutting, and more especially if there were laminæ of clay, the superimposed strata often struck near the base of the wall; and a retaining wall on that side not only had to support the normal lateral thrust of the mass of earthwork immediately behind, but it had also a long wedge-like piece of earth impinging against the earth at the back of the wall, so that in many cases the thrust on the wall at the one side must be something like double the amount that it was on the other; because on the other side, the dip being away from the wall, the wall was subject only to the lateral thrust of the earthwork in its rear. The Author had stated that the failures of many dock walls did not illustrate entirely the ordinary lateral thrust of earthwork; but Mr. Redman thought that such cases as the failure of the walls constructed by the late Mr. G. P. Bidder, Past-President Inst. C.E., at the Blackwall entrance to the Victoria docks, the partial failure of the same engineer's walls in the enlargement of the Surrey docks, the similar catastrophe at the Victoria dock, Hull, in the work designed by the late Mr. John Hartley, and possibly also a similar movement in the South West India Dock wall, were all clearly attributable to lateral thrust. It might be said that the foundation was not taken down deep enough, and consequently the wall did not resist that thrust; but having had a somewhat extended and varied experience for a

Mr. Redn great number of years, he certainly was not prepared to endorse the dogma that a dock wall or a river wall must necessarily be so strong as to resist a head of water, or in width at the base equal to one-half the height. In the first place, the water ought not to be allowed to come behind the wall. There were exceptional cases, perhaps, where that could hardly be avoided; but it seemed to him that laying down such a tenet was a premium for loose engineering, imperfect supervision, and lavish expenditure. He had himself, in the lower reaches of the Thames, erected some of the heaviest embankment walls on the river, where the thickness was only ⅓ of the vertical height. It was true that the walls were founded on the best possible foundation—Thames ballast—and it was done as tide work; and the greatest possible care was also taken to keep the backing up to the same level as the wall, and indeed rather above the wall. In fact, the great mistake in retaining walls was the imperfect supervision exercised over the backing. If the backing were put in with tolerably fair material in thin horizontal layers and brought up in that way, the lateral thrust was reduced to a very small matter. The Author had stated that the decayed timber wharves on the Thames and in other neighbourhoods showed that the lateral thrust must be over-estimated; but it should be remarked that the skin might be stripped off the face of the earthwork, assuming that no water was coming against it, and it would stand, because from the length of time and consolidation of material, there was no lateral thrust. The example quoted of the breakwater at St. Katharine's, Jersey, appeared to be a case in point. He had nothing to do with the inception or execution of that work; but he thought the wall might be taken down and the heart of the pier would still stand. He would refer to two great Metropolitan failures which were well known, and which might be interesting in illustration of this subject. One was that of Greenwich Pier and the other of the Island Lead Works. The Greenwich Pier was constructed nearly half a century ago from the design of a local architect, Mr. Martyr. It was one of the heaviest embankments on the Thames; it had the greatest depth of water up to it, and it was, being in the hollow of the reach, subject to every condition of weather. The base was formed by cast-iron piling and cast-iron sheeting between, constituting a half-tide dam, and concrete was got in behind. Upon the top of the concrete there were large 6-inch York landings and a very solid, heavy brick wall. There were also outer piles, and the work was constructed in the best possible way. The case was somewhat complicated by the fact that a large amount of land-water came

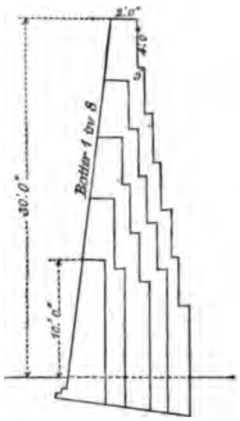
Mr. Redman. down and a large amount of spring-water. There was a common sewer running through the heart of the work, and a large tidal reservoir for the Ship Hotel. The whole of that work, with the exception of the two returns and quoins and a small portion in front of the Ship Hotel, slipped into the river during the night some forty years back. The late Mr. Chadwick, who built the Hungerford suspension bridge, entered into a contract to restore the work on his own plan, acting as engineer and contractor, and he restored the portion that had failed with timber-bearing piles and a solidly-constructed brick wall. Shortly after the demise of Mr. Chadwick, the restored portion showed signs of failure, and Mr. Redman was called in by the Pier Directorate, and the matter resulted in a lawsuit, and a large sum of money was obtained in compensation. All he did was to bleed the pier by inserting a cast-iron pipe with a self-acting flap at the eastern end, and to remove and substitute with better material some part of the backing. He proposed driving land-tie piles at the back and some in front; but on consideration with the Directorate, it was thought that driving piles might be a ticklish operation. That was twenty years ago, and up to the present time the work had remained in the same state. It had settled somewhat at the eastern end, and there were reopened fissures in front, so that the movement had not altogether ceased. The wall of the Island Lead Works designed by the late Mr. R. Sibley, M. Inst. C.E., was the pioneer of cast-iron wharfing; and from the fact of the Limehouse cut having been deepened too close up to it, the wall failed. As the Author had said, that case did not illustrate the absolute lateral pressure of earthwork, because this work, as long as it was not meddled with, stood satisfactorily. The leaseholders called in Mr. Redman on that occasion, and the freeholder consulted Mr. Bateman, Past-President Inst. C.E., and the late Mr. N. Beardmore, M. Inst. C.E., very wisely—to avoid a lawsuit—constructed a wall deeper down, to their satisfaction.

r. Atkinson. Mr. W. ATKINSON agreed with Mr. Lewis's remarks with respect to the large amount of masonry or brickwork that the Author had introduced in the cases of the metropolitan railways. He had been much struck with the proportion of $\frac{1}{3}$ of the height for the mean thickness of a wall; but looking at the diagrams, and taking into consideration what he had seen of the work, there was a very good explanation. It struck him that on the Metropolitan railway, where property was so valuable, the batter which the late Mr. Brunel introduced of 1 in 5 would be extremely inconvenient: either the roadway would have

Mr. Atki

to be narrowed, or a great deal more property would have to be taken, than would be otherwise necessary. No doubt the Author would be able to say whether that had any influence in the carrying out of the work. Then with regard to the general question of the walls and their failure due to bad foundations, it struck him that the two things should be entirely separate; that the foundation should be treated as a foundation, and that having been made sufficiently strong, a properly proportioned wall should be placed upon it. He rather gathered from the Paper that the two points had been taken as a whole, and that the Author meant, "I have a bad foundation, and I will make the whole to stand." If that were so, it would have been better policy to have made a foundation of concrete, and then put in a wall sufficiently strong. With regard to the question of theoretical calculation, there was a French formula which agreed remarkably with what might be considered the ordinary practice. He himself had put up a good many walls, not perhaps as distinct retaining walls, but in connection with bridges on 48 miles of the Mid Wales railway, and he had found practically that the $\frac{1}{4 \cdot 5}$ of the height for the mean thickness stood perfectly well. In that case, it was to be borne in mind that there were two elements in addition to the theoretical calculation, namely, the projection of the footings where there was so much leverage, which was not taken into account in the calculation, and the weight of the earth resting on the projections or steppings at the back of the wall, Fig. 44. That, of course, aided the wall very materially; in fact it might be called so much masonry saved. At all events, if merely the theoretical thickness of the wall was given, then, with the projections of the footings, and the weight of earth on the steppings, there was a very good margin of safety; and in that way the wall was erected with $\frac{1}{4 \cdot 5}$, or 33 per cent. less than the dimension advocated by the Author, and was a good and sufficient wall. One point with regard to walls was brought to his notice when in Canada, namely, the thickening of the top to resist frost. In ordinary circumstances the practice would be to put about 2 feet at the top, and then about 4 feet down a projection of 9 inches, and so on; but in Canada, on account of the penetration of the frost, it

Fig. 44.



Scale, 16 feet = 1 inch.

Mr. Atkinson. had been found necessary to keep the top of the wall much thicker than was the practice in England.

Mr. Law. Mr. H. LAW desired to add his testimony to the great value of the facts laid before the Institution. It was upon such facts, the result of actual experience, that the most valuable data were formed. In the early part of the Paper the Author had pointed out that the formula usually adopted—Coulomb's—did not give the results which were obtained when loosely heaped materials were placed at the back of the wall; but a little consideration would show that that formula never was intended to apply to such cases. Coulomb's theorem distinctly took into account the adhesiveness or coherence of the ground, and then determined, depending upon the line on which the ground separated, what the amount of pressure would be; and the value to the engineer was, that it determined what was the maximum which that pressure could be. Putting w = the weight of a cubic foot of the soil in lbs., h = the height of the wall in feet, r = the limiting angle of resistance of the soil, s = the angle between the line at which the soil separated and the horizontal, and P = the horizontal pressure in lbs. of the soil against the wall, then Coulomb's theorem might be thus expressed:

$$P = \frac{w\,h^2}{2} \cdot \cot s \cdot \tan (s - r).$$

Now in the case of a fluid, r, or the limiting angle of resistance, vanished, and consequently the result was that the co-tangent of s into the tangent of s became equal to unity, and

$$P = \frac{w\,h^2}{2}$$

When the ground was sufficiently coherent to stand vertically, then the angle of separation being 90° the co-tangent of s became nothing, and the pressure became nothing. When the line of separation coincided with the limiting angle of resistance or r, that was to say, when there was a mass of earth sufficiently coherent not to break of itself, and lying upon a bed which happened to be at the limiting angle of resistance, the tendency of the earth to slide was exactly overcome by its friction, and r being equal to s, the tangent vanished, and P again became nothing. Now, between those two values there was a certain angle at which, if the ground separated, it would produce the maximum pressure, and that was given by Coulomb's theorem, which proved that when the line of separation bisected the angle made by the limiting angle of resistance with the vertical, then $\cot s = \tan (s - r)$, and Mr. Law.

$$P = \frac{w h^2}{2} \cdot \cot^2 s,$$

and the maximum pressure was obtained. The great value of the formula was to show, with a given weight of earth and a given limiting angle of resistance, what the maximum pressure was. It could not exceed the value expressed by making s half the angle between the limiting angle of resistance and the vertical. This formula could not be applied in the case of loose materials, as sand and gravel, because it was impossible for such materials to stand at any other than their limiting angle of resistance; and under such circumstances there would be upon the wall only a comparatively small pressure, due to the unbalanced weight which remained from the efforts of the sand and gravel to roll down upon itself. He wished to direct attention to one or two interesting exemplifications of excessive pressure which were met with in the works for the Thames tunnel. The Rotherhithe shaft, 50 feet in diameter, was built upon the surface and sunk by excavating beneath. That operation was successful until a depth of 40 feet was reached, and then, although the exterior surface had been made perfectly smooth by being rendered, it became earth-bound, and notwithstanding the earth was excavated to a depth of 2 feet around the whole margin, and 50,000 bricks were placed upon the top as a load, making the total weight 1,100 tons, and water was allowed to rise inside, the shaft refused to sink any farther. Now, taking the weight of the ground at 120 lbs. per cubic foot, which was about what it was on the average, and taking the coefficient of friction at 0·67, it would be found that a limiting angle of resistance of about 31° 15′, and a line of fracture of about 27° 30′, would show, by Coulomb's theorem, that the shaft would be bound, and therefore the practical result was quite in accordance with the pressure given by the formula. The Author had mentioned a case of some heavy clay which had a pressure equivalent to a fluid pressure of 107 lbs., and if that clay was taken as having a limiting angle of resistance of about 5° or 1 in 10, and the weight was assumed to be 130 lbs. per cubic foot—which clay of that description might very well have—the formula would give 107 lbs. for the fluid pressure. He therefore thought these circumstances fully showed that where ground was coherent and adhesive, Coulomb's theorem applied. In the progress of the Thames tunnel there had been some remarkable

Mr. Law. cases of excessive pressure, where of course the weight of the water was superadded to that of the ground. He knew many instances of poling boards, 3 feet in length, 6 inches wide, and 3 inches thick, supported by two poling screws bearing against cast-iron plates, being split lengthwise by the pressure of the earth against the outer surface.

Mr. Bernays. Mr. E. A. BERNAYS said the inconsistencies alluded to in the Paper tended to make it still more interesting than it otherwise would have been. There were few engineers who had carried out works, but were conscious of inconsistencies in their own practice and theories. The Author had quoted Voisin Bey, the distinguished French engineer, as saying that he had rarely seen a long wall straight, and Mr. Bernays' experience fully confirmed that view. When it was straight the chances were there was a superabundance of material to keep it so. If it was run fine, as the calculations advised, the chances were 50 to 1 against having a straight wall. With regard to Mr. Brunel's section of wall, no doubt if it had a good foundation it was very strong for the material in it. It not only had a rising abutment to bring the pressure down upon the foundation, but it had counterforts, which added greatly to the strength of the wall, although of late they had gone out of fashion. He considered that it was nearer 10 feet at the base than 5 feet, as, if the counterforts were 10 feet apart, the wall was, practically, a solid wall. If made of concrete instead of brickwork, it would probably be found better to make it solid at once. The batter considerably added to the strength, but it was not without practical disadvantages. The greater the batter the greater the disadvantage. The tendency of the batter was to throw the side of a vessel farther away from the wall than need be, and to entail cranes with longer jibs, as well as the use of much larger fenders. Iron ships were now all covered with anti-fouling composition, which might easily be scraped off. With all its disadvantages he would rather have a smaller batter for practical purposes when ships were to lie alongside the wall. He had seen a wall of this section in Woolwich Dockyard (built, he believed, by Sir John Rennie, Past-President Inst. C.E.), partially pulled down and refaced by the late Mr. James Walker, Past-President Inst. C.E., for the purpose of deepening the dock. It was about 30 feet deep, and was increased to about 38 feet by putting a thin wall in front of it. In pulling down such walls he had always found that the backing in settling hung upon the set off, and he had seen holes under the backing large enough for a man to creep in. He would not say that they

Mr. Bernays

were objectionable in other respects, but he preferred a battered back to a retaining wall to square sets off. The Author had alluded to a wall that he was building, and had characterised it as "exceptionally heavy." But for that expression he would have been quite content to sit still; he hoped to be able to show that the exceptional heaviness was justified by the exceptional circumstances under which it was being built. He did not think much of experiments with peas and pea-gravel, and bits of board a foot square, when he had to deal with big walls. The Author stated (p. 183) that "experience has shown that a wall ¼ of the height in thickness, and battering 1 inch or 2 inches per foot on the face, possesses sufficient stability when the backing and foundation are both favourable." Unfortunately for dock engineers it rarely happened that either the foundation or the backing was favourable, and it was still rarer to find both favourable. This fact made the inconsistencies that really showed the thoughtful way in which the Paper had been written. There was no attempt to square theory with practice; but the Author had candidly pointed out where theory broke down in referring to the retaining walls of the Metropolitan railway, and at the approach to the Euston station, and in other instances. He agreed with the Author that the Sheerness river wall had perhaps a greater moment of stability than any other wall in the world. The section assumed that the pile foundation would stand, though he doubted its stability; but if it would stand, half the thickness of the wall would have been ample. He did not know sufficient of the nature of the subsoil at Sheerness to be able to decide the point. He had been told that in many cases the piles were 40 feet long; and a few years ago, when a new caisson was put in the basin at the yard, there was great fear lest it would come forward when the water was let out. That was merely an instance of the cases where provision must be made for very different calculations from those which were set out in any Table. He quite agreed with the Author that no calculations would meet cases where the work was exceptionally difficult. In most instances, engineers were called upon to make docks and other great works in the worst kind of soils, such as estuaries, beds of rivers, or in deep alluvial deposits. The reason that he strengthened the wall at Chatham was because the original design showed symptoms of weakness, and several of the walls yielded about 10 or 12 inches. He did not say that that was entirely the fault of the walls, because the foundation was far from satisfactory, and there was a decided forward movement of the piles; but it was evident that the wall, for the greater

Mr. Bernays. part of the area, was not at any rate too strong for the work. When, however, he came to the east end of the works, where he had to build a wall 1,050 feet long without a single break, and with 35-feet depth of soft mud to excavate through, it was absolutely necessary to strengthen the wall, and it was decided to build it entirely of concrete, in order to be able to give the additional strength without additional cost. He was asked some years ago what angle this mud would assume at rest, and the answer he gave was that it would not lie flat. The basin at Chatham was being built in an old arm of the river Medway, and the basin generally stood in the middle of the river bed. On each side of it the mud was 35 feet deep on the average, and in some cases the distance to be filled in with backing was 500 feet. The whole of that backing had to be laid on this sliding mud, which brought pressure on the wall in a way far beyond anything he had ever seen allowed for in any calculation. If he understood correctly, Mr. Giles had thought it necessary to provide, not only for the backing, but for a pressure of water nearly as high as the water in the dock. He did not agree with Mr. Redman that it was possible to get the walls built up so as to prevent water percolating. At Chatham there was a standing level of the water in the district, and wherever excavations were made to that depth water was found. The bottom of the basin was 20 or 25 feet below that level, and the water exerted a pressure just as if there was an ocean of that depth behind it. Then it was sometimes necessary to put heavy buildings, as at the Victoria Dock Extension, where large sheds loaded with heavy goods were placed from 100 to 150 feet from the wall. No one would say that such sheds would not exercise a great pressure on the adjacent wall. He would be happy to show the Author the wall at the Chatham Dockyard Extension, and abide by that gentleman's judgment, whether "the exceptionally heavy wall" was not necessary to meet the peculiar conditions of the case.

Mr. Giles. Mr. A. GILES, after what Mr. Bernays had said about the pressure of mud behind dock walls, thought he was quite justified in adhering to the assertion he made many years ago, that a dock wall ought to be strong enough to carry a head of water behind it equal to its height. He cordially joined in thanking the Author for the Paper, but he considered it would have been better described as, "On the Stability of Retaining Walls." The Author had given many examples of dock and retaining walls, but after throwing over the theoretical calculation as to the pressure of earth against a wall, he said that in ninety-nine cases out of a hundred walls failed from faulty foundations, and not from want of strength in themselves. The various diagrams afforded rather congratulatory evidence of his own theory, that practically all the thick walls had stood, and most of the thin walls had given way. Referring to the old Southampton dock wall, mentioned as having been built forty years ago, that had only a thickness of 32 per cent. at the base, but with the counterforts it was 35 per cent. That wall had been pushed forward, but it never came down; but it was saved by taking out the wet soil at the top and covering the top by a timber platform. Another wall which he had built had been referred to. That had a thickness of 45 per cent. at the base, and an average thickness of 41 per cent. Surely that wall ought to be strong enough to resist not only the pressure of water behind it, but even the pressure of mud that would not stand at a level. It had not stood without moving—not from any want of strength in the wall, but simply from the want of adhesion in the foundation. At Whitehaven, the thickness of the wall was 37 per cent. at the base, and the mean thickness 31 per cent., and it had stood. At Avonmouth these values were respectively 59 per cent. and 42 per cent. There was a very fine example at Carlingford of a wall with the base only 32 per cent. thick, and a mean thickness of 24 per cent.; but what could be said about the wall at Sheerness with a height of 40 feet and a base of 43 feet? It was stated that that wall had not moved, and Mr. Bernays had contended that it ought not to move; but he did not think any engineer of the present day would dare to design, or to contemplate building, a wall of that character, because a wall of similar height in ordinary ground could be built for £60 a yard, while that wall would cost £300 a yard. In many instances it was not the inherent weakness of the walls that caused them to fall, but the slip at the bottom, and that was shown in Fig. 17 by the necessity which arose for thickening the wall so as to make the strength as 62 to 24. After all, the wall required still further strengthening by putting buttresses in front of it. The conviction he had arrived at was, that it was not generally the fault of the wall that caused the failure; but the fault of the foundation—not only that the foundation was not wide enough to give sufficient hold on the ground, but that there was not sufficient footing in front of the wall to enable the soil upon which the wall rested to sustain the weight. It was the same as if a cliff, 30 or 40 feet high, were put on tender soil. The soil would not be strong enough to bear it, and consequently the edge of the cliff would settle into the soil, the soil would burst up in front, and the Mr. Giles.

Mr. Giles. pressure from behind would then make itself felt. He had seen that process take place in a wall which he had constructed, and it was only saved by putting buttresses in front of the footings. Something had been said in the Paper about allowing a margin for contingencies. In that matter every engineer must decide for himself; but he thought that from ¼ to ½ was rather a large margin, and he would suggest that the thickness of a retaining wall ⅓ of the height would be, in nine cases out of ten, ample to resist the backward pressure; but he would insist upon having a large buttress in front of the foundation, carried down as deep as the lowest foundations of the wall. He was at a loss to imagine what the extraordinary projection in front of the wall at Marseilles (Fig. 25) meant. It might be that it was intended to hold the bottom down; and it was in that direction he would recommend retaining walls should be strengthened. A remark had been made about the necessity of having the upper part of dock walls nearly perpendicular, because of the friction of ships rubbing against them, and the inconvenience of ships lying at some distance from the quay at the coping level. That was perfectly true, and he believed it had been a common practice, in designing walls where there was a curved batter, to make the centre of the curve level with the coping, by which a certain depth of almost perpendicular work was obtained from the coping level. He believed that was the correct principle; but he would urge particularly that, in making dock walls, the foundations should be much wider than they were in general, and that the bulk of the buttress should be in front of the face of the wall, and not behind. In all walls, the excavation at the bottom should be carried down perpendicularly, with as little disturbance of the soil as possible; because in excavating the work, it was better to fill up the void so made, that there should be no tendency to slip after the wall was put in. There was another point which he thought was not sufficiently considered by engineers in designing dock walls. They were apt, when the excavation had been carried out, to think that they had got a good foundation; but he cordially agreed with the Author when he used the word "lubricating." Notwithstanding what Mr. Redman had said, he did not think it was possible to keep water from getting behind a dock wall: he believed there was a point at which water would always be found: it would get up from the bottom, or through the wall somewhere; and that being so, he thought that all the soil upon which the wall stood must be soddened and lubricated to a certain extent. He knew of instances where

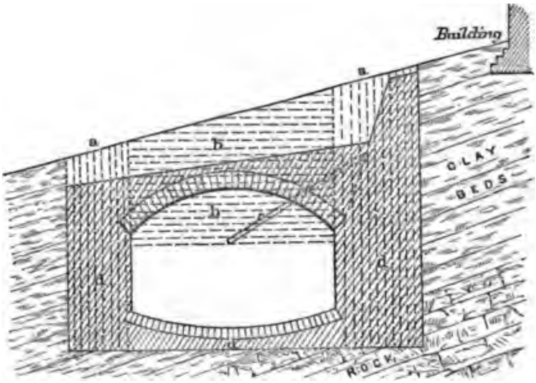
Mr. Giles. walls had stood for many years; but all at once the moment of lubrication had arrived, and they slipped in. He could only account for it by supposing that there was a tendency on the part of walls to get surrounded with water, by which they became of less specific gravity, or that the soil got saturated, and therefore less able to bear the load put upon it. He would therefore urge upon all his professional brethren who had the conduct of dock works, to look particularly to the front of the walls to ensure their stability.

Mr. Bousf Mr. W. R. Bousfield desired to make one or two remarks, from the theoretical standpoint which the Author had deprecated. He referred to a point in which theory and practice would agree, viz., as to the effect of water behind a retaining wall. If there was an interstice of even an inch the effect on the wall would be exactly the same as if the whole ocean were behind it; therefore, a dock wall should be made to withstand a pressure equal to the hydrostatic pressure due to a head of water of the height of the wall. He wished to ask if the Author could explain, somewhat more at length, the effect of lateral pressure in General Burgoyne's experiments, for he did not think the remarks were quite sound. If the lateral pressure of the ground, consisting, say, of loose rubble, was greater than the hydrostatic pressure, the fact of water being admitted would not make the slightest difference, because the water pressed equally on the earth and on the wall in opposite directions, so that the earth would be kept back by the pressure, and the difference between the lateral pressure and the hydrostatic pressure would be exerted by the earth on the wall. The only effect would be in the distribution of the pressure, which instead of being taken by the points of stone alone, would be distributed by the water over the whole wall. If the lateral pressure of the soil was less than the hydrostatic pressure, then of course, if water was admitted behind, it would exert upon the soil a force greater than the pressure of the soil on the wall; therefore, supposing the soil were rigid, the lateral pressure of the soil would be kept entirely off the wall. Of course, in practice, there were many points at which the pressure was excessive, so that, on the whole, the maximum pressure to be provided for would generally be rather more than the hydrostatic pressure.

Mr. Bened Mr. E. Benedict described a retaining wall (Fig. 45) lately put up at Ryde. The ground was sidelong and at the foot of a clay hill, the strata dipping towards the work, and with a heavy building close to it. By cutting a trench and filling it as soon as possible with solid concrete in Portland cement carried up to the

Ir. Benedict. surface, the clay, which weathered rapidly when exposed to the air, was covered without delay, the concrete became agglomerated with the clay at the back, and did not allow any percolation of water. The excavation in front of the wall then proceeded without any movement of the ground occurring, and he thought that none would take place. Eventually a covered way was formed on the lower side of the wall, the arch of which was designed so as to form a continuous flying buttress.

FIG. 45.



Mr. Baker. Mr. B. BAKER, in reply, observed that he agreed, to some extent, with almost everything that had been said in the discussion, and he considered that the criticism had been very fair. He was glad indeed that he had elicited so many valuable opinions on the subject. Mr. Airy spoke about the difference in the cohesion of different clays. He had noticed the same thing himself, not merely in different clays but in the same clay. A railway cutting often refused to stand at a less slope than 4 to 1, and yet the same clay, after being tempered a little, might be found in an adjoining brick-kiln standing with a vertical face. He had nothing to say with regard to Mr. Vernon-Harcourt's comments, except that he agreed with almost everything that gentleman had said. Mr. Barry had made some sensible remarks about the advantage of using struts to retaining walls, and he thought it would be a good thing, in many cases, to imitate the old architects of cathedrals, and substitute flying buttresses for a heavy mass of materials. Some time ago he designed some very cheap sheds upon that principle, in which the roofs were light concrete arches supported by flying buttresses. Mr. Barry had referred to the

Mr. Baker

cracks at the angles of some of the piers of the Metropolitan District railway retaining walls. He was satisfied that these did not arise from pressure, but from chemical action, because they occurred only in the case of certain bricks, and he knew where the bricks came from, and had every reason to mistrust them. He had sometimes found scaling occur all over the face of a wall, though of course the angle was always the weakest point, and nature always tried to round off an angle, as might be seen in Cleopatra's Needle, where there was no square angle. Mr. Lewis had described a wall designed by the late Mr. Brunel, but he did not approve of it, for reasons that had been set forth by Mr. Bernays. He himself had found exactly the same thing, namely, that in pulling down work where there had been the slightest settlement, the earth at the back did not rest on the offsets, indeed, not infrequently, a man could push in his arm between the offset and the filling. It was therefore idle to maintain, as Professor Rankine and others did, that the earthwork resting on the offset was as good as so much masonry. There was no economy in putting in the offsets, and he attributed the stability of apparently light walls so constructed to the pressure of the counterforts and the good quality of the backing. Mr. Redman had directed attention to the fact that there was an increased thrust when the ground at the back was sloping. No doubt that was so; and a case of that sort was referred to in the discussion on Mr. Constable's Paper at the American Society of Engineers, where the ground at the back was sloping rock. When the wall was first put up and the backing was filled in, the whole mass came forward in consequence of the wedge of earth sliding down the surface of the rock. The masonry was pulled down, the rock cut in steps, and the wall rebuilt of the same thickness. Pig-iron to the extent of 55 tons to the lineal foot was then placed behind the wall, and it stood perfectly well, though the thickness was less than 30 per cent. of the height. That was sufficient evidence of the importance of stepping the ground at the back. Mr. Atkinson said he thought it would be better to make the foundation satisfactory first and then to build a thin wall on the top of it. At page 181 of the Paper that point was alluded to and the answer given. Mr. Law had submitted a formula, and drawn deductions from it, which he could not follow; but it seemed to him that the contention was that a loose material exerted less thrust on the wall than a more compact material, and that Coulomb's theory was not applicable to loose soil. He did not agree with that view in theory, and Lieutenant Hope's experiments showed that that was not so

Mr. Baker. in practice, at least on a small scale. Lieutenant Hope placed a board behind the pressure-board at such an angle as to include Coulomb's wedge of maximum thrust between the two boards, and found that the lateral pressure was quite as much when the board was at the slope of repose, 1½ to 1, as when it was at half the angle. There was hardly any difference whether the board was horizontal or at a slope of ½ to 1, or at any intermediate slope. Then it had been remarked with regard to one of his examples, in which the stability of the wall was equal to the fluid pressure of 107 lbs. per cubic foot, that theory would indicate the pressure to be about that amount; but a statement in the Paper did not seem to have been noticed, that the wall never had that pressure on it, but failed by sliding forward. Of course it might have slid forward with a pressure of 40 lbs. per cubic foot, but since the struts had been put in, there was not the slightest indication of movement, and therefore the moment of stability could not have been deficient. Mr. Bernays seemed to imagine that the expression "excessively heavy" reflected on the design of the Chatham dock wall, but the intention was the reverse. He entirely approved of it, and considered that it was a well designed and creditable engineering work in every respect. It was one that he should imitate. His contention throughout the Paper was that formulæ did not apply to such works, and although he began the Paper with a diagram he set it up merely in order to knock it over. Mr. Giles considered that instead of the limits of ¼ to ½ of the height for the thickness of a retaining wall, ⅓ should be the limit with a buttress in front of the toe; but he did not think that that was the practice which had been followed in the Southampton Dock Extension, where the limit, he believed, was nearer ½ than ⅓—45 per cent. The curious slope projection in Fig. 25 was really an apron to protect the foundation, which was of clay. The clay was very hard when laid bare, and a sort of shield was put there to prevent its softening. He believed the same thing had been recommended by a committee of engineers in the case of the Belfast dock, where the wall failed; but it was applied too late, or the conditions were different, because the wall came forward notwithstanding.

Correspondence.

Mr. Barl

Mr. W. H. Barlow, Past-President, thought both as regarded the principles set forth in the Paper, and the practical examples which had been given, that the subject was worthy of careful study. It had been thoroughly gone into, and great discrimination exercised in the consideration of the various cases cited.

Mr. Flam

Mr. A. Flamant said the Author had cited and analysed sixty-five experiments or observations, from which he drew the conclusion, that the actual thrust of earths was generally inferior to that indicated by formula; and that walls constructed on the hypothesis of no factor of safety at all, in reality possessed such an element of security at least equal to 2. Conversely, that walls maintained their equilibrium when of a thickness less than $\frac{1}{2}$ that dictated by theory. These facts, and many others that had gone to make up his personal experience, had convinced the Author that the laws which governed lateral thrust were not at present on a satisfactory basis.

This conclusion might be correct if the friction of the earth against the inner side of the wall were neglected, as Rankine implicitly neglected it in the case under consideration, of a level mass retained by a vertical wall. This supposed the inner side of the wall to be infinitely polished; that was, that the pressure acted normally, after the manner of a fluid. But in his "Essai théorique sur l'equilibre des massifs pulvérulents,"[1] published by the Royal Academy of Belgium, Professor Boussinesq had shown what Messrs. Maurice Lévy and de Saint Venant had already demonstrated, that that hypothesis, which greatly simplified the solution of the problem, did not give exact results unless (the surface of the earth retained being level) the inner side of the wall, instead of being vertical, formed an angle equal to half the complement of the interior angle of friction; or the wall being vertical, when the earth retained was not level, and its upper surface followed the angle of repose of the strata. In the case of a horizontal mass of earth retained by a vertical wall, Rankine's theory gave the true value of the pressure of the earth, at least when the interior angle of friction was equal to 45°, but it was erroneous where it concerned the direction of this pressure, which it considered as acting perpendicularly to the wall, that was to say, horizontally, while in reality it formed an angle with the ir. Flamant. wall equal to the angle of friction of the earth against the wall. From that resulted, in point of stability, an important consequence; the inclination of the pressure diminished its moment in respect of the outer edge, and allowed of a diminution of the thickness of the wall.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. li., p. 277, for an abstract of this article.

It had been shown by Professor Boussinesq in the same essay, that Rankine's theory took account of the interior equilibrium of the earth comprised between the plane of the top of the mass retained, and another plane passing by the bottom edge of the wall, and making an angle with the vertical which, where the surface of the mass retained was level, was equal to half the complement of the natural slope. But the whole of the earth comprised between this plane and the inner side of the wall, vertical or inclined, was subject to other laws, in which had to be considered the friction of the earth against the wall.

The determination of the conditions of equilibrium of a retaining wall exacted, therefore, the knowledge of the friction of the earth against the inner side of the wall. As in general this surface was sufficiently uneven, it gripped a thin layer of the earth retained, and it was against this bed that the remainder of the unstable mass rested. The friction of the soil against the wall might therefore be considered as equal to its own inherent friction. In enunciating this hypothesis, Professor Boussinesq found that the relation of the breadth b of the base to the height h of a rectangular vertical wall of weight (*densité*) Π', would resist the pressure of a mass of earth of density Π, level on the upper surface, and having a natural slope, making with the horizontal an angle ϕ, and would be expressed by the formula,

$$\frac{b}{h} = \frac{2}{3} \cdot \frac{1}{\tan\phi + \sqrt{\tan^2\phi + \frac{4}{3}\frac{\Pi'}{\Pi}\frac{1}{K\cos\phi}}},$$

in which (the case being that of a level mass retained by a vertical wall)

$$K = \tan^2\left(\frac{\pi}{4} - \frac{\phi}{2}\right)\frac{\cos\left(\frac{\pi}{4} - \frac{\phi}{2}\right)}{\cos\left[\phi - \left(\frac{\pi}{4} - \frac{\phi}{2}\right)\right]}.$$

Mr. Flamant had applied this formula to the first case cited by the Author (broken and screened macadam retained by a wall of pitch-pine blocks, p. 145). Here the angle of repose having been 1·2 to 1, the expression would be

$$\tan\phi = \frac{1}{1\cdot 2}; \text{ whence } \phi = 39^\circ\ 48'.$$

Mr. Flam

From this he had deduced a value for K = 0·205, and using this for the preceding expression, he had got $\frac{\Pi'}{\Pi} = \frac{49}{101}$; giving, as the Author had done, an increase of density of the wall to allow for the excess of its height over that of the macadam, he had found the result to be $\frac{b}{h} = 0\cdot22$. The height of the mass retained being in this case 3 feet 9 inches, the thickness, b, of the wall should have been 0·22 thereof, viz., 9 inches 11 lines, or say 10 inches. The wall in this case was therefore bound to resist.[1]

A similar process might be applied to the other cases cited by the Author, in proof that the pressures were notably less than those indicated by the old theory. With these cases, the Author had given others, extremely interesting from an engineering point of view, in which he had recorded instances of the complete overturning, or of the occurrence of disquieting movements in walls which appeared to have been built of ample strength. The Author seemed to infer from these the hopelessness of arriving at any simple formula for the construction of a retaining wall. Mr. Flamant thought that here the Author confounded the question of stability of the walls with that of solidity of the foundations. Nearly all the walls that had yielded to the pressure of earthwork owed their failure to defective foundations. The theory of the pressure of earthwork, and the stability of retaining walls, supposed always that the foundations were absolutely immovable and presented infinite resistance. It was therefore not fair to make the theory responsible for defaults which arose from unstable foundations. No doubt theory alone could not replace practical experience, and the Author was right in saying (p. 163) that "if an engineer has not had some failures with retaining walls, it is merely evidence that his practice had not been sufficiently extensive;" but this dictum was equally applicable to all other branches of engineering. Experience could only be bought at the price of failure. If, on the one hand, theory only took account of ideal conditions, impossible of attainment in practice, and disregarded the thousand various incidents which compelled the attention of the engineer, it, on the

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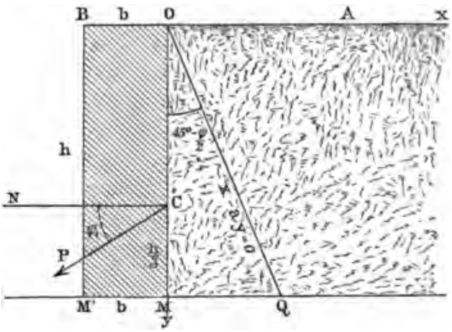
[1] At the same time, according to Prof. Boussinesq, the value 0·22 was but a low limit for $\frac{b}{h}$; a better limit based on equations (19) and (24), or (18) and (24) of Prof. Boussinesq's contribution would be, tan $\phi' = \frac{1}{1\cdot2}$, $\frac{b}{h} = 0\cdot256$, which would give b = 11 inches 6 lines. The true minimum value would therefore be about 10 inches 9 lines.

Mr. Flamant. other hand, afforded powerful help in facilitating the search of the true causes of failures, and to enable him to generalise from experimental data which, if they could not be linked together by theory, were only isolated facts, of no practical utility.

Professor Boussinesq. Professor J. BOUSSINESQ thought it would be appropriate to supplement the demonstrations of the formulæ applied by Mr. Flamant to the Author's calculation of the examples of retaining walls by some new considerations. He would confine himself to the supposititious case of a level mass of homogeneous material, A O M, retained by a vertical wall, O M M′ B. For the case of a mass of a given inclination or of curved upper surface, retained by a wall of given inclination or of curved batter, reference might be made to Nos. 43 to 48 of his "Essai théorique sur l'equilibre des massifs pulvérulents, comparé à celui de massifs solides; et sur la poussée des terres sans cohésion."[1]

FIG. 46.



1. He would call Π the weight of the earthwork per unit of volume, N_x, N_y, T, the three components, normal and tangential, of the pressure exerted per unit acting at a point (x, y) of the interior of the mass on an element of the vertical plane parallel to the wall, and on an element of the horizontal plane, elements respectively perpendicular to the upper surface O A, taken for the axis of x, and of the lateral profile O M, taken as an axis of y. The normal components, N_x, N_y, would be regarded, according to the usual practice in molecular mechanics, as positives when they represented tension, consequently they would here be uniformly negatives, seeing that they represented pressure. Lastly, he

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[1] Published by Gauthier-Villars, 55 Quai des Grands Augustins, Paris.

Professor Boussine

would call ϕ the angle of interior friction of the earthwork, and the angle of friction of the earthwork against the wall ϕ_1, and he would assume

$$a = \tan\left(45^\circ - \frac{\phi}{2}\right) = \sqrt{\frac{1 - \sin\phi}{1 + \sin\phi}} \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

The three unknown elements of the problem being thus N_x, N_y, T, three indefinite equations would be required. These would be, firstly, the two relations

$$\frac{d\,N_x}{d\,x} + \frac{d\,T}{d\,y} = 0, \quad \frac{d\,T}{d\,x} + \frac{d\,N_y}{d\,y} + \Pi = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

representing the equilibrium of translation in the direction of x and y, of rectangular element of volume; hence the formula

$$\sin^2\phi = \frac{(N_x - N_y)^2 + 4\,T^2}{(N_x + N_y)^2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

used by Rankine to show that the equilibrium was everywhere on the point of being destroyed, or that, if account were taken at every point of the different plane elements which crossed there, and of the pressures which they there exerted, the angle ϕ was properly the greatest made by those pressures to the normals of the corresponding plane elements.

To these three equations would be added, First, the special relation—

$$(\text{for } y = o)\ N_y = 0,\ T = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

showing that at the free surface O A the exterior pressure was nil (since that of the atmosphere might be disregarded). Secondly, the condition, also special,

$$(\text{for } x = o)\ \frac{T}{-N_x} = \tan\phi_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

which should be verified for the whole face O M of the wall, in order that the earth should be then at the point of sliding against that face.

It was natural first to consider the simplest forms of equilibrium, those where the mechanical condition of the earthwork was the same at all points equidistant from O A, or to depend, not on x but only on y; which would be to attribute to the face O M the precise degree of smoothness, or the particular angle ϕ_1 of exterior friction necessary to ensure that the earthwork should behave in the neighbourhood of the wall as it behaved farther

Professor Boussinesq. from it, that was as if it were inert, or as if the presence of the wall induced no perturbation. This Rankine had done, insomuch that his formula implied the supposition in question relatively to ϕ_1. The functions N_x, N_y, T, did not in that case depend upon x; equations (2) and (4) gave at once $N_y = -\Pi y$, $T = 0$. The relative (3) hence became $\frac{N_x}{N_y} = \frac{1 \pm \sin \phi}{1 \mp \sin \phi}$. But it was here a question of a limit of equilibrium, by compression in the vertical direction of y, with hindrance (*détente*) from the horizontal direction of x, where N_x was visibly inferior to N_y in absolute value. $\frac{N_x}{N_y}$ would therefore have to be taken as equal to $\frac{1 - \sin \phi}{1 + \sin \phi}$, or, in accordance with (1), $N_x = a^2 N_y$. Rankine had thus put

$$N_x = -\Pi a^2 y,\ T = 0,\ N_y = -\Pi y \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

But the relation (5) then became $0 = \tan \phi_1$, or $\phi_1 = 0$, so that his formula had to be taken, in the case under consideration of an earthwork A O M, as expressly allowing of no coefficient of exterior friction, or of supposing that the wall was infinitely polished.

2. As this supposition was never realised, it was evident that the values (6) of N_x, T, N_y only applied, in the case of an earthwork, at a certain distance from the wall, and that as O M was approached they would have to be replaced by others depending simultaneously on x and y. Even the integration of equations (2), (3), (4) and (5), effected without supposing $\phi_1 = 0$, but so that the expressions N_x, T, N_y were reduced to (6) for x large enough, would give these values. This integration, for which he would refer to Nos. 46, 46 *bis*, and 47 of the work already cited, was only practicable when ϕ_1 was sufficiently small. It gave the following results:—

$$(\text{for } x > a y)\ N_x = -\Pi a^2 y,\ T = 0,\ N_y = -\Pi_y \quad . \quad . \quad . \quad . \quad (7)$$

$$\left.\begin{aligned} (\text{for } x < a y)\ N_x &= \frac{-\Pi a^2 (y + x \tan \phi_1)}{1 + a \tan \phi_1},\ T = \frac{\Pi a \tan \phi_1 (a y - x)}{1 + a \tan \phi_1}, \\ N_y &= \frac{-\Pi (y + x \tan \phi_1)}{1 + a \tan \phi_1} \quad . \quad . \quad . \quad . \end{aligned}\right\} \quad (8)$$

So that if, in the earthwork, the plane O Q making an angle $45° - \frac{\phi}{2}$ with the face O M of the wall, or being expressed by $x = a y$, the part A O Q would answer to Rankine's law; but the small part Q O M exacted the more complicated expressions (8).

Professor Boussinesq

Virtually, it was found at once that these values (7), (8) satisfied the relations (2), (4), (5), and that further they varied continuously as the surface O Q was traversed; that was to say, when they passed from one part to another, making $x = a\,y$. The expressions (7) still satisfied the indefinite equation (3), and it only remained to see that the expressions (8) verified it. For that he would call ϕ' the greatest of the angles made—by expressions (8)—at every point (x, y) of the region Q O M by the pressures there exerted according to the different directions with the normal to the plane elements which they solicited. Formula (3) gave for the value of the square of the sine of these angles—

$$\sin^2\phi' = \frac{(N_x - N_y)^2 + 4\,T^2}{(N_x + N_y)^2} = \left(\frac{N_x - N_y}{N_x + N_y}\right)^2 + \left(\frac{2\,T}{N_x + N_y}\right)^2,$$

or, according to the expressions (8) for N_x, N_y, T,

$$\sin^2\phi' = \left(\frac{1 - a^2}{1 + a^2}\right)^2 + \left(\frac{2\,a^2}{1 + a^2}\right)^2 \tan^2\phi_1 \left(\frac{1 - \dfrac{x}{a\,y}}{1 + \dfrac{x}{y}\tan\phi_1}\right)^2.$$

According to (1) the relations $\dfrac{1 - a^2}{1 + a^2}$, $\dfrac{2\,a^2}{1 + a^2}$ were equal respectively to $\sin\phi$, $1 - \sin\phi$, so that there resulted—

$$(\text{for } x < a\,y)\ \sin^2\phi' = \sin^2\phi + (1 - \sin\phi)^2 \tan^2\phi_1 \left(\frac{1 - \dfrac{x}{a\,y}}{1 + \dfrac{x}{y}\tan\phi_1}\right)^2 \quad (9)$$

As the ordinate y was positive in all earthworks, the fraction $\dfrac{1 - \dfrac{x}{a\,y}}{1 + \dfrac{x}{y}\tan\phi_1}$, which depended upon the relation $\dfrac{x}{y}$, decreased from 1 to zero when the region Q O M was traversed horizontally in a direction from the back of the wall, that was to say, where y remaining constant, x was made to increase from zero to $a\,y$. It followed that the value of $\sin^2\phi'$, equal to $\sin^2\phi$ on the limit O Q, and constant at all points of each of the planes equated by $\dfrac{x}{y}$ = const., increased a little in the neighbourhood of O M, and was found, at O M itself, to have attained to $(1 - \sin\phi)^2 \tan^2\phi_1$, Professor Boussinesq. a total increase which might properly be neglected for the second order of smallness, if ϕ_1 were of the first order.

But if, on the contrary, ϕ_1 was finite, it would be seen that the formulæ (7) and (8) would not apply absolutely except in the case of an earthwork slightly heterogeneous, where the angle of interior friction—constant and equal at distances from the wall greater than *a y*—would acquire, in the neighbourhood of the wall, the slightly higher values denominated ϕ'.

To evaluate approximately the average amount of heterogeneity so defined by the formula (9), it would be necessary to take from (9) $\cos^2 \phi'$ and $\tan^2 \phi'$. And lastly, to extract the square root by the binomial theorem, by neglecting the square of the small ratio of the last term of (9) to the principal term $\sin^2 \phi$. This would give sensibly

$$\frac{\tan \phi'}{\tan \phi} = 1 + \frac{(1 - \sin \phi)^2 \tan^2 \phi_1}{2 \sin^2 \phi \cos^2 \phi} \left(\frac{1 - \dfrac{x}{a\,y}}{1 + \dfrac{x}{y} \tan \phi_1} \right)^2 \quad . \quad (10)$$

The mean value of the variable factor $\dfrac{1 - \dfrac{x}{a\,y}}{1 + \dfrac{x}{y} \tan \phi_1}$, when x was there made to increase from zero to *a y*, was evidently less than that $\frac{1}{2}$, which it would have if the denominator $1 + \frac{x}{y} \tan \phi_1$ did not increase as the numerator diminished. *A fortiori*, therefore, the value of the square of this factor, comprised between zero and 1, would be much less than the arithmetic mean, $\frac{1}{2}$, of its two extreme values. Nevertheless, as the greatest values of the points very near the wall would be, by reason of this nearness, of slightly greater influence on the pressure which the wall supported, and which was the principal object in view, it would be necessary to allow to them, other things being equal, slightly more importance than to the others. It was for this reason that only $\frac{1}{2}$ had been allowed as the mean value of the factor in question. Formula (10) therefore gave

$$(\text{mean}) \frac{\tan \phi'}{\tan \phi} = 1 + \left(\frac{1 - \sin \phi}{\sin 2 \phi} \right)^2 \tan^2 \phi_1 \quad . \quad . \quad . \quad (11)$$

In the frequent case where ϕ was supposed equal to 45°, and con-

Professor Boussines

sequently $\tan\phi = 1$, $\sin 2\phi = 1$, $\sin\phi = \frac{1}{\sqrt{2}}$ this ratio became—

$$\left.\begin{aligned}(\text{for } \phi = 45^\circ)\ \tan\phi' = 1 + \left(\frac{3}{2} - \sqrt{2}\right)\tan^2\phi_1 = \\ = 1 + 0\cdot 086 \tan^2\phi_1\end{aligned}\right\}. \quad (12)$$

It would be seen that, even attributing to ϕ_1 its greatest possible value, which was that, ϕ, of the angle of interior friction (or supposing the inner face of the wall to be rough enough to retain a thin layer of earth acting as the wall), the difference $\tan\phi' - \tan\phi$ would not be, in general, more than 0·086, and would only correspond to an increase in the angle of friction, $\phi' - \phi$, equal to 2° 22′. This increase was so small in comparison with $\phi = 45^\circ$, that it would not vitiate in practice the application of formula (8) to a homogeneous earthwork having an angle of interior friction ϕ; as the amount of heterogeneity neglected was not greater than many accidental defaults of homogeneity which could not be considered.

At the same time it was to be remarked that formula (8), though exact in regard of exterior friction, required the supposition, although dependent, as had been seen, on the hypothesis of an interior friction slightly too great near O M, that the retaining walls would be too slight, since it tended to exaggerate the tendency of earth to interior slipping. Rankine's formula, on the contrary, gave the exact expression for internal friction, but implied the condition of an external friction too small, or even of no amount, generally diminishing considerably the influence of friction in upholding the wall, and consequently implying an increase in the thickness of the latter.

3. He now proposed to show the result of applying formula (8) to determine the total pressure of the earthwork against the inner surface O M of the wall, and especially the moment of this thrust in relation to the inner and outer edges in the direction of the point M′, on which the wall tended to pivot when overturning. Making $x = 0$, the values of $-\mathrm{N}_x$ and of T, would become the normal and the tangential component (on O y) of the pressure supported by a unit of area of a given element of O M. These components were consequently—

$$\left.\begin{aligned}(\text{for } x = 0)\ \ -\mathrm{N}_x &= \frac{\Pi a^2 y}{1 + a\tan\phi_1} = \frac{a^2 \Pi y}{\cos\phi_1 + a\sin\phi_1}\cos\phi_1, \\ \mathrm{T} &= \frac{\Pi a^2 y \tan\phi_1}{1 + a\tan\phi_1} = \frac{a^2 \Pi y}{\cos\phi_1 + a\sin\phi}\sin\phi_1;\end{aligned}\right\} \quad (13)$$

fessor ussinesq.

and the thrust per unit of area, equal to $\frac{a^2}{\cos\phi_1 + a\sin\phi_1}\,\Pi y$, varied at different depths, as would be the case in a fluid of specific weight equal to $\frac{a^2}{\cos\phi_1 + a\sin\phi_1}\,\Pi$; only instead of being normal to the wall it would be inclined to the horizontal at a constant angle ϕ_1. This difference of direction not preventing its parallelism at different points, its total value from top to bottom on the unit of length of the wall could be calculated as for a fluid. Consequently the resulting pressure P would pass by a point C of the face O M, situate at a third of the height, h, of the face; it would have the direction, C P, inclined at an angle ϕ_1 below the horizontal C N, and its value would be $\frac{a^2}{\cos\phi_1 + a\sin\phi_1}\,\frac{\Pi h^2}{2}$, or—

$$P = K\,\frac{\Pi h^2}{2} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (14)$$

if, to shorten the process,

$$K = \frac{a^2}{\cos\phi_1 + a\sin\phi_1} \quad . \; . \; . \; . \; . \; . \; . \; . \; . \; . \; . \quad (14\text{A})$$

or, since $a = \tan\left(45^\circ - \frac{\phi}{2}\right)$,

$$K = \tan^2\left(45^\circ - \frac{\phi}{2}\right)\frac{\cos\left(45^\circ - \frac{\phi}{2}\right)}{\cos\left[\phi_1 - \left(45^\circ - \frac{\phi}{2}\right)\right]} \quad . \quad (15)$$

It would be observed in the case, common enough, when $\phi = 45^\circ$ this value of K would be found the same for $\phi_1 = \phi$ (which was the hypothesis to be assumed in practice) as for $\phi_1 = 0$. Thus the pressure would have the value attributed to it by Rankine, only instead of being normal it would be inclined 45° below the horizon.

Reverting to the general case, the horizontal component of the pressure P would be $K\,\frac{\Pi h^2}{2}\cos\phi_1$, and, as it had for the lever arm $\frac{h}{3}$, in respect of the point M′, its moment was $K\,\frac{\Pi h^3}{6}\cos\phi_1$. The vertical component of the same pressure $= K\,\frac{\Pi h^2}{2}\sin\phi_1$. If the base of the section O M M′ B of the wall, that was the

Professo Boussin

thickness of the wall, were called b, the lever-arm of this component in respect of M′ was $-\,b$, and its moment $-\,\mathrm{K}\,\frac{\Pi\,h^2\,b}{2}\sin\phi_1$. There thus resulted

$$\text{Moment of pressure} = \mathrm{K}\,\frac{\Pi\,h^2}{2}\left(\frac{h}{3}\cos\phi_1 - b\sin\phi_1\right). \quad (16)$$

For the limit of equilibrium of the system it was necessary that this value should attain exactly that of the moment itself of the weight of the wall in respect to M′. He would call $\Pi'\,h$ the weight of the wall in respect of a unit of area of its base, so that Π' should be its specific weight for a height h, or if its upper surface coincided with that of the earth retained. The weight of the unit of length of the wall would be $\Pi'\,b\,h$, and supposing that it were divided uniformly, or directed according to the vertical passing through the middle of the thickness b, there would result for its moment $\Pi'\,\frac{b^2\,h}{2}$. The condition of equilibrium whence should be deduced the minimum thickness of the wall would be

$$\frac{\Pi'\,b^2\,h}{2} = \mathrm{K}\,\frac{\Pi\,h^2}{2}\left(\frac{h}{3}\cos\phi_1 - b\sin\phi_1\right);$$

or, multiplying by $\frac{b}{\Pi\,\mathrm{K}\,b^2\,h\cos\phi_1}$,

and ordinating,

$$\left(\frac{h}{b}\right)^2 - 3\tan\phi_1\cdot\frac{h}{b} - \frac{3\,\Pi'}{\Pi\,\mathrm{K}\cos\phi_1} = 0 \quad \ldots\ldots \quad (17)$$

If this equation were solved in respect of $\frac{h}{b}$, and then were excluded, a negative root foreign to the question,

$$\frac{h}{b} = \frac{3}{2}\left[\tan\phi_1 + \sqrt{\tan^2\phi_1 + \frac{4\,\Pi'}{3\,\Pi\,\mathrm{K}\cos\phi_1}}\right]. \quad . \quad (18)$$

a relation whence K could be found by equation (15).

Such was the formula showing the ratio $\frac{h}{b}$ of the height h of the earthwork to its minimum thickness b, and which would consequently allow of this minimum thickness being found.

4. To show how the ratio $\frac{h}{b}$ was dependent upon the angles ϕ to

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ϕ_1 of the interior and exterior friction, the value of K (14A) might be used, remembering that $a = \tan\left(45° - \frac{\phi}{2}\right)$ or that $\frac{1}{a} = \tan\left(45° + \frac{\phi}{2}\right)$. The result would be—

$$\left.\begin{array}{l}\frac{h}{b} = \frac{3}{2}\Big[\tan\phi_1 + \\ +\sqrt{\tan^2\phi_1 + \frac{4\Pi'}{3\Pi}\tan\left(45°+\frac{\phi}{2}\right)\left[\tan\left(45°+\frac{\phi}{2}\right)+\tan\phi_1\right]}\Big]\end{array}\right\} \quad (19)$$

It would be observed that the second member increased when ϕ or ϕ_1 increased, and even that, if the inner face of the wall was not extremely smooth, the ratio $\frac{h}{b}$ obtained by supposing $\phi_1 = 0$, as Rankine expressly supposed, would be too small, or its inverse $\frac{b}{h}$ much too great. Practically, retaining walls were always rough enough to compel the adhesion of the contiguous layer of earth, and ϕ_1 would have to be taken as equal to ϕ.

Generally, where $\phi = 45°$ and consequently $\tan\phi = 1$, $\tan\left(45° + \frac{\phi}{2}\right) = 1 + \sqrt{2}$, there resulted—

$$\left.\begin{array}{r}(\text{for } \phi = \phi_1 = 45°)\ \frac{h}{b} = \frac{3}{2}\Big[1 + \sqrt{1 + 4\Big]\left(\frac{4}{3} + \sqrt{2}\right)\frac{\Pi'}{\Pi}} = \\ = (\text{very nearly})\ \frac{3}{2}\left(1 + \sqrt{1 + 11\,\frac{\Pi'}{\Pi}}\right)\end{array}\right\} \quad (20)$$

While if ϕ_1 were taken as equal to 0,

$$\frac{h}{b} = 3\sqrt{\left(1 + \frac{2}{3}\sqrt{2}\right)\frac{\Pi'}{\Pi}} = (1 + \sqrt{2})\sqrt{3\,\frac{\Pi'}{\Pi}}\ .\quad .\ (20\text{A})$$

For $\frac{\Pi'}{\Pi} = 1$ this second value would only be $\frac{h}{b} = 4 \cdot 18$; then the value (20) was $\frac{h}{b} = 6 \cdot 69$, or 1·6 time greater. If the masonry were heavier than the earth, or if $\frac{\Pi'}{\Pi} > 1$, this ratio of 1·6 of the two values would diminish, by approaching the limit $\sqrt[4]{2} = 1 \cdot 19$ for $\frac{\Pi'}{\Pi}$ infinitely, and it would on the other hand increase indefinitely if $\frac{\Pi'}{\Pi}$ became less than 1, seeing that at

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the limit $\frac{\Pi'}{\Pi} = 0$ formula (20) gave $\frac{h}{b} = 3$ or $b = \frac{1}{3} h$, while Rankine's formula gave $\frac{h}{b} = 0$ or $b = \infty$.

5. It would have been all along seen that equations (8) and consequently (19) slightly exaggerated the influence of the interior friction, and inferred a value of b a little too small. To be quite safe and to obtain a limit of b too high, values might be given to ϕ and to ϕ_1, slightly less than the true ones, by calculating these lesser values as if the maximum of the variable angle of interior friction ϕ', supposed by the formulæ, were just equal to the true value of the angle of friction of the earthwork in question; for in that case the latter would be more stable than the theory supposed. Well, the greatest value of ϕ' given by formula (9) was when $\frac{x}{y} = 0$, and it was definite for the relation—

$$\sin^2 \phi' = \sin^2 \phi + (1 - \sin \phi)^2 \tan^2 \phi_1 \quad . \quad . \quad . \quad . \quad (21)$$

which, multiplied by $\cos^2 \phi_1$ easily gave—

$$(\sin \phi - \sin^2 \phi_1)^2 = \cos^2 \phi_1 (\cos^2 \phi_1 - \cos^2 \phi^1) \quad . \quad . \quad (22)$$

The second member being essentially positive, since the first one was, ϕ_1 would always be greater than ϕ', as would be imagined, seeing that the angle of exterior friction ϕ_1 could not exceed that of the interior friction, ϕ', of the layer of earth next the wall. Therefore, from equation (22), where ϕ' would be the real and known value of the angle of interior friction, and where ϕ_1 was comprised between zero and ϕ', positive values for $\sin \phi$, which by (21) would themselves always be less than $\sin \phi'$. These values, introduced into the expression $\sqrt{\frac{1 + \sin \phi}{1 - \sin \phi}}$ of $\tan \left(45^\circ + \frac{\phi}{2}\right)$ would only allow of there remaining from the second member of (19) but a single variable, ϕ_1, to be determined. This would, for instance, be chosen so as to make the second member of (19), a lower limit of $\frac{h}{b}$, the largest possible. For this, it would evidently be necessary to take from the two values of $\sin \phi$ given by (22) the greater, still making—

$$\sin \phi = \sin^2 \phi_1 + \cos \phi_1 \sqrt{\cos^2 \phi_1 - \cos^2 \phi'} \quad . \quad . \quad . \quad (23)$$

It would, moreover, be found that, by differentiating this ex-

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pression of $\sin \phi$ in reference to ϕ_1, its derivative or the sign of the factor—

$$\cos^2 \phi' - 2 \cos \phi_1 \left(\cos \phi_1 - \sqrt{\cos^2 \phi_1 - \cos^2 \phi'}\right)$$
$$= \cos^2 \phi' \left[1 - \frac{2 \cos \phi_1}{\cos \phi_1 + \sqrt{\cos^2 \phi_1 - \cos^2 \phi'}}\right],$$

which was always negative, seeing that $\cos \phi_1 + \sqrt{\cos^2 \phi_1 - \cos^2 \phi'}$ was less than $2 \cos \phi_1$. Thus ϕ varied inversely to ϕ_1; it decreased, virtually, from $\phi = \phi'$ to $\phi = \text{arc} \sin (\sin^2 \phi')$, when ϕ_1 increased from zero to ϕ'. As a consequence the two variables ϕ_1 and ϕ, on which depended the expression (19) of $\frac{h}{b}$, would change in contrary directions, and these opposite variations would produce two inverse effects on the corresponding values of $\frac{h}{b}$. It would be conceived (seeing, moreover, the impossibility of this function (19) attaining the value it would have if ϕ and ϕ_1 equalled ϕ') that there might result from this the existence of a maximum of the function at the instant when one of the two effects precisely balanced the other. To determine this, it would doubtless be more convenient, now that it was known that $\sin \phi$ could not vary more than from $\sin^2 \phi'$ to $\sin \phi'$, to consider ϕ as an independent variable and to replace, in (19), $\tan \phi_1$ by its value $\frac{\sqrt{\sin^2 \phi' - \sin^2 \phi}}{1 - \sin \phi}$, deduced from (21). But the determination of this maximum not appearing to be easy, Professor Boussinesq would content himself with choosing a value of ϕ which would, *à priori* and in general, not appear to favour either of the two results. In short, he would take $\phi_1 = \phi$ in equation (22). This, which if sines were taken instead of cosines, and if, first, the factor $1 - \sin \phi$ were suppressed, and secondly, the term $- \sin^3 \phi$, common to both members, would give—

$$2 \sin^2 \phi - \sin^2 \phi' \sin \phi - \sin^2 \phi' = 0;$$

and next, by solving—

$$\sin \phi = \sin \phi_1 = \frac{\sin \phi' + \sqrt{8 + \sin^2 \phi'}}{4} \sin \phi' \quad . \quad . \quad (24)$$

Such was the equation which would give the values of ϕ and of ϕ_1 for the expression (19) $\frac{h}{b}$.

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If, for instance, $\phi' = 45°$ or $\sin^2 \phi' = \frac{1}{2}$, then—

$$\sin \phi = \sin \phi_1 = \frac{1 + \sqrt{17}}{8} = 0{\cdot}6404, \ \phi = \phi_1 = 39° \ 49';$$

and substituting formula (19) instead of the value (20)—

$$\frac{h}{b} = \frac{3}{2}\left(0{\cdot}8338 + \sqrt{0{\cdot}6952 + 8{\cdot}457 \frac{\Pi'}{\Pi}}\right). \quad . \quad . \quad (25)$$

For $\frac{\Pi'}{\Pi} = 1$ there also resulted $\frac{b}{h} = 5{\cdot}79$ instead of $6{\cdot}69$ obtained by formula (20). The true value being comprised between these two would equal about 6, and the minimum thickness of the wall should be about $\frac{1}{6}$ of its height.

Another inferior limit of $\frac{h}{b}$, preferable to the foregoing when $\frac{\Pi'}{\Pi}$ was much less than unity, was obtained by taking $\phi_1 = \phi'$, and, as in (22), $\sin \phi = \sin^2 \phi'$. For instance, for $\phi' = 45°$ this gave $\phi_1 = 45°$, $\phi = \text{arc} \sin \frac{1}{2} = 30°$, $\tan\left(45° + \frac{\phi}{2}\right) = \sqrt{3}$, and further—

$$\frac{h}{b} = \frac{3}{2}\left[1 + \sqrt{1 + 4\left(1 + \frac{\sqrt{3}}{3}\right)\frac{\Pi'}{\Pi}}\ \right] = \frac{3}{2}\left(1 + \sqrt{1 + 6{\cdot}309\frac{\Pi'}{\Pi}}\right) \quad (25\text{A})$$

If $\frac{\Pi'}{\Pi} = 1$ this formula gave $\frac{h}{b} = 5{\cdot}56$, a less advantageous limit than the preceding one of $5{\cdot}79$.

Professor Gaudard.

Professor GAUDARD, of Lausanne, stated that the Author had collated a large number of observed facts of the highest interest relative to retaining walls, selected under the most varied conditions. Nothing could be more to the purpose than his recital, in order to indicate what a preponderating part was played by local conditions; consequently how great the faculty of discernment, the minute observation of the nature of the soils, of the lie of the beds, of their cohesion, of the action of springs, &c., dominated in matters of construction; and to what lengths, now of boldness, now of extreme prudence, one might be led, according as these elements were favourable or unfavourable.

It was also not to be wondered at that the Author declared war against the false theorists, who essayed to include every case in a formula; and still more so against the false practicians, since he asserted (and it might readily be believed) that 99 per cent.

Professor Gaudard. of the failures of walls were due to defective foundations. Certainly foundations came within the domain of the practician, where much algebra would scarcely be hazarded.

Doubtless the *aide-mémoires*, or repertories of cut-and-dried formulæ, however useful they might be to those endowed with clear perception, that was to those who had also studied their demonstration, might readily induce error in the case of persons simple enough to attribute to those works an authority absolute and infallible. Because any one had culled from such a source a formula professing to give, for instance, the stability of a wall subjected to earth-pressure, would he venture to believe that all was given that was required? and that he was absolved from the necessity of considering the question of foundations, which was quite distinct from the pivoting round a fixed base?

The stability of a wall comprised four subjects for study, individually complex, and how much more so in combination! There was first the foundations, a distinct art, and, he would repeat, a purely practical one. Next the examination of the geological conditions, no longer of the subsoil, but of the side strata to be sustained; their cohesion or friability, dryness or saturation, sliding beds, &c. In some cases the soil would stand vertically without any wall; in other cases, owing to a water-bearing stratum, no wall could resist. Further, there was the question of the mechanical properties of semi-fluids—where general laws certainly did exist, whether they were received or not—to which he would refer later on. There remained the nature of the resistance opposed by a masonry work. In practice this last consideration was generally simplified by disregarding the adhesion of the mortar. Doubtless, as had been remarked by the Author, the cements now employed were so excellent that it would be quite proper in many cases to take their holding power into account. At the same time, for works which should endure for centuries and resist the weather and defaults of maintenance, the usual practice of extreme prudence would always be highly commendable.

The greater part of the facts in the Paper had been deduced, not from experiments with models, where it was generally sought to eliminate as much as possible all elements but the one to be studied—but from the behaviour of executed works, consequently from cases where all the complex elements coexisted. It was sufficiently evident that no one would dream of combining such results into equations. The single general conclusion which might be ventured was, as the Author had enunciated, a very cautious and reserved statement of the proportion of thickness to height

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which appeared in most cases to comply with the exigencies of practice; and even then subject to the express condition that the foundation should be immovable, that the subsoil should not be softened nor mined by springs. It was indispensable to abstract this last element, which required special and separate consideration.

Having conceded so much, he would ask, could it be affirmed that no mathematical expression for the thrust of earths could ever be of use? In many cases the soils to be sustained presented to the eye nothing sufficiently irregular to prevent the opinion that they might be regarded as homogeneous and friable; perhaps they might possess a certain cohesion, but precarious. Well, if rain could reduce such soils to a state of mud, it was under this form, unstable and dangerous, that they must be regarded. This was exactly the problem, perhaps a little ideal, but nevertheless of considerable utility, which mathematicians had endeavoured to solve, and no one would doubt that if the correct solution could be found it should be registered by engineers. In Professor Gaudard's opinion the question was still open, and the Author, with his spirit of penetration, seemed well qualified to seek its elucidation. But it would be necessary that he should undertake, if he had the leisure, a comparison, not of the one formula given, but of complete theories, with experiments not merely casual and containing unusual conditions, but systematic, or at least considering only a selection of the facts in his possession, in which the phenomenon should be complicated neither by the cohesion of the soil nor by the adhesion of the mortar on the base of the part resisting. From this point of view, although the Author had treated the theorists a little severely, he had not pierced their armour, neither had he himself furnished sufficient light; he had simply demonstrated—what no one doubted—that no theory could be applied correctly to a case outside the conditions for which that theory was itself correct, the more so when it was reduced to a maimed condition.

Moreover, the formula, criticised by the Author, was by no means admitted as correct by mathematicians. It was only a simplified expression adapted to ordinary practice, and notoriously containing a large margin of safety—which, indeed, was the Author's view of it. It was deduced from the theory of Poncelet by neglecting the friction of the soil against the wall, that was, by becoming voluntarily inexact, but in the direction of safety. If, therefore, it was desired to show how far Poncelet's theory was correct, it must be considered in its entirety, Professor Gaudard. which involved another value for the thrust, and, above all, a direction for that force inclined to the normal of the wall. Further, Poncelet's theory was itself no longer considered as sufficient. It was based on the assumption of a prism of earth of maximum thrust acting by friction, after the manner of a wedge with plane sides, against the wall and the undisturbed subsoil. Rankine showed the way to a better conception, which had been followed up and amended by other scientists, notably by Mr. Lévy. Until proved to the contrary, it must be allowed that they had approached the truth; only there remained still to be considered under what form, at once sufficiently simple and sufficiently exact, this method could finally be reduced to practice. The experiments already made with sandy substances and movable shutters, as those of Ardant, of Audé, and of others, far from discouraging them, appear in fact to have given a new impetus to theoretical research. At the same time, as the Author had remarked, these experiments were delicate, and whether from their own difficulty or from the force of preconceived ideas, or of dissimilar preoccupations, it was easy enough to arrive at phenomenal results. It was precisely this that, even in the imaginary cases of soils absolutely pulverulent and homogeneous, made him despair of the possibility of any generalisation from experience alone, unaided by the light of theory; for practice only accumulated particular facts, and did not connect them together. Indeed it had not, so far, even shown the variation of thrust of a mound of sand which, instead of lying horizontally at the crest of a wall, sloped at some arbitrary inclination. Here certainly must be a law, and it would be well to know it. For a long time mathematicians had supplied various solutions of this problem, which merited more or less attention. If the angle of repose, as a function of the physical property of the soil, were taken for a point of departure, it would be in order to begin with a palpable datum, easily measured experimentally, and not for the puerile amusement of providing a road to traverse between an auxiliary and secondary hypothesis and the result sought for, viz., the thickness of the wall, which the Author seemed to say might be obtained hypothetically at first sight, without further examination. Engineers must not be too contemptuous of mathematics—an instrument at once so delicate and powerful. Certainly he would not pretend that mathematics would attain to the same preponderance in Engineering as in Astronomy; but what would this last science be, and consequently the art of navigation, with the single assistance of the telescope, and without the equations of celestial mechanics?

Professor Gaudard.

On a branch of science as abstruse as the thrust of soils it was not too much to concentrate all the powers of experiment and logical deduction, especially on the latter.

He would conclude by an observation of detail. He was not in accord with the Author when he appeared to regard as a gratuitous hypothesis the addition to the wall of the weight of the earth superposed to the offsets at the back (*redans du parement intérieur.*) This process, of which the application was only eventual, was a simple artifice of the composition of forces, to which recourse was had to complete the value of the thrust, when the latter, instead of being considered at once on the face of a battered or stepped wall, had to be evaluated on the vertical section stretching from the interior footings through the soil. In that case, instead of having, when considering the equilibrium, to consider two forces only—thrust on the wall itself and weight of the wall—there would be three: auxiliary thrust against a prism of earth, weight of the prism, and weight of the wall. The thrust against this latter was obtained as the resultant of the two former forces; but it sufficed perfectly, if preferred, to consider the auxiliary thrust by itself as being in equilibrium with the compound weight. As regarded the fact observed by the Author, that the wall in overturning detached itself from the soil, that must, without doubt, be looked upon as a consecutive phenomenon, belonging to the dynamic phase—when the wall was in place the soils thrusting against it touched it.

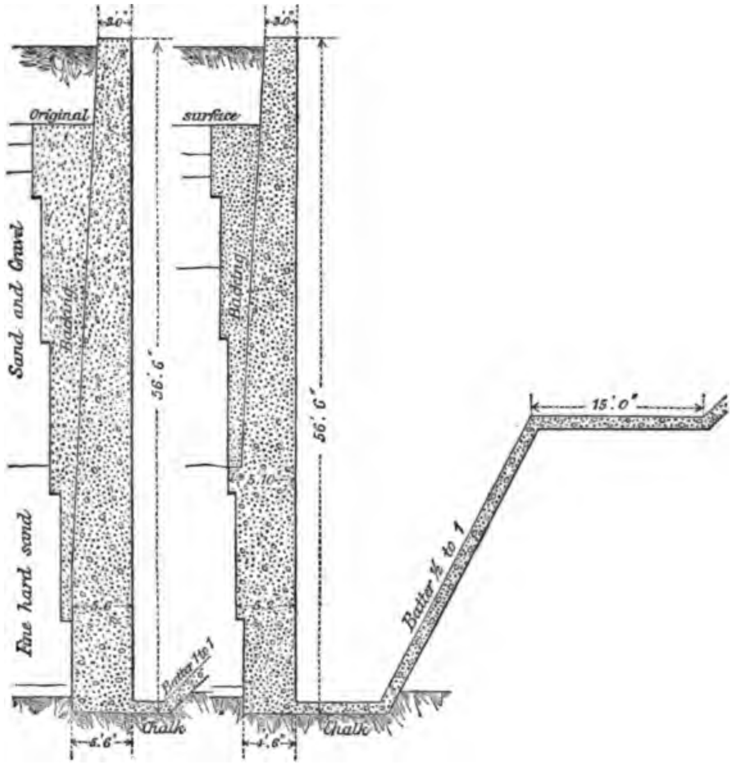
While, therefore, he thought that sincere acknowledgments were due to the Author for his rich and interesting collection of observed facts, he took the liberty of regarding the present Paper only as an instalment, relating to abnormal, heterogeneous cases, outside the scope of any general law. He would be glad when the Author would be led to throw some light on the mechanical laws governing the thrusts of pulverulent and homogeneous soils.

Mr. Hawk

Mr. J. CLARKE HAWKSHAW remarked that dock walls had not only to act as retaining walls and to be of sufficient strength to carry the ground and backing below quay level, but they must be strong enough to carry heavy loads placed on the quay. One of the Bute dock walls at Cardiff, though strong enough to act as a retaining wall, had failed and moved about 13 feet into the dock owing to iron ore having been placed on the quay behind it. All dock walls could not, of course, be designed to carry unlimited loads of iron, but no engineer could anticipate what loads might be put on a quay; and as an ample margin of strength should awkshaw. always be left in designing a dock wall, it would seem to be unnecessary to enter in any great detail into the weight due to the nature of the backing. At the same time the facts given by the Author, and the further facts which his Paper had elicited, were interesting and valuable even when applied to dock walls. If the pressure due to each sort of earthwork could be ascertained the margin left for quay loads would at any rate be known.

. Livesey. Mr. George Livesey, remarked that he had erected a wall, Fig. 47, for the South Metropolitan Gas Company, at their Old Kent Road Works, for a gasholder-tank, 216 feet in diameter and 55 feet 6 inches deep. The wall was designed to be 5 feet 6 inches thick at the bottom, gradually tapering to 3 feet thick at the top, thus necessitating the filling in of the space between the

Fig. 47.


3.0
3.0
Original
surface
Sand and Gravel
Backing
Backing
56'.6"
56'.6"
15'.0"
5.10
5.6
5.2
Fine hard sand
Batter 1/4 to 1
Batter ½ to 1
Chalk
Chalk
5'.6"
4'.6"

Section of wall as designed.

Section of wall as executed.

back of the wall and the face of the excavation, from the bottom to the top, with the fine sand obtained from the excavation. Mr. Liv
As it was impossible to make this backing as solid as the original undisturbed soil, it was advisable to have as little backing as possible, particularly in the case of a rendered tank, where the full pressure of the water was exerted upon the face of the wall itself. The excavation for a tank was of necessity wider at the top, owing to the system of timbering with 9-inch deals and walings, each successive frame of the deals or runners being placed within that next above it, the face of the second tier being 8 inches in front of the first and so on. The excavation of the ring, therefore, consisted of a series of steps, 8 inches wide, at intervals of 12 or 14 feet, according to the length of the runners, and as the wall was reduced in thickness as it rose, whilst the trench became wider, the amount of backing increased as the work approached the ground line. The soil for about 20 feet above the chalk on which the tank was built consisted of fine sand, which would stand vertical if the water was all drained out of it, but became running sand if the excavation was attempted whilst it remained saturated with water, which was its normal condition. Fortunately the contractors provided ample pumping power to thoroughly drain the ground in advance of their excavation, and as a consequence the sand stood firm at the back of the runners. Resting upon this fine sand there was a bed of sharp sand and gravel, averaging 20 feet in thickness, which was used for the concrete. This would not stand at all without support from the runners. Then came some loamy stuff; and on that the surface market-garden mould, altogether about 48 feet, overlying the chalk. Seeing that the lowermost bed of sand offered such a solid support to the concrete, it was thought advisable to dispense altogether with artificial backing where the sand existed, and to fill in the concrete solidly against it. Hence the projections at the back of the wall, which if unexplained, would appear so strange, there being two inverted sets off, each 8 inches in depth, as shown in the figure of the finished tank. The wall thus thickened in an upward direction to the top of the fine sand, instead of diminishing in thickness as at first intended. The intended thickness at the bottom was to have been 5 feet 6 inches, and the diameter of the tank 216 feet, for a 212-feet gasholder. But it was found that, with the sand so firm, and by building close up to it, it would be safe to reduce the thickness at the bottom to 4 feet 6 inches, thus increasing the diameter of the tank to 218 feet, and the gasholder to 214 feet. The total depth was 55 feet 6 inches, of which the rest blocks, seventy-two

Mr. Livesey. in number, made entirely of concrete, occupied 18 inches, giving a total working depth of 54 feet. The sharp sand and gravel would not stand at a less angle than 1 to 1, which in the original design was the angle shown for the whole of the cone; but finding the lower bed of sand so firm, it was thought possible to reduce the amount of excavation, and the angle was accordingly altered to 6 inches to 1 foot for the lower part of the cone, thus effecting a double saving, viz., the cost of excavation, and the trouble of disposing of the excavated material. The benching half way up the cone was consequently increased from a width of 4 feet, to that shown in the second section. The gravel and sand above this line were valuable, and as much as possible taken out; the cone was covered with concrete 12 inches thick.

It was difficult to form any estimate of the earth pressure on this cylindrical concrete wall; probably in that part where the concrete was filled in close to the fine solid sand to the height of about 20 feet from the bottom, the pressure of the earth was slight; but from the point where the backing of earth commenced to the top, a distance of about 45 feet, a very considerable pressure would be exerted. The backing consisted of the fine sand, well punned or rammed in thin layers, and watered, it being most essential in a rendered tank to make this backing as solid as possible. The tank wall was completed in about six months, when the concrete, being comparatively green, had to support the entire pressure of the earth, which it did without showing the least sign of weakness.

Mr. Meÿer. Mr. C. H. Meÿer directed attention to the case of retaining walls which frequently had to support bad ground, such as mud or other treacherous material, especially dock or river retaining walls. He could name several cases where treacherous ground of this nature exerted what might be looked upon as fluid pressure to a high degree, not at all to be compared with that caused by shingle or even weak clay, and where the weight of the material was from 100 to 120 lbs. per cubic foot. He thought that mud was so little to be depended on, that in the long run it would have no angle of repose, that was without tendency to exert pressure by slipping, short of almost horizontality, or where it would not exert lateral pressure by an inability to bear its own weight without squeezing, and he should much like to know the Author's views on such a case.

Mr. Prince. Mr. H. Prince had been much surprised to find the profession accepting the principle that piles in a foundation were for the purpose of carrying weight; that they transmitted directly the weight of a structure through a soft unreliable stratum to a more

Mr. Prince.

solid one below; or in other words, that piles were looked upon as so many legs on which the structure was to stand. This appeared to be a mistaken and unscientific theory. He had been taught, and still maintained, that the object to be kept in view in using piles in a foundation was the consolidation of the strata or soil on which the structure was to rest. The portion of strata to be consolidated was first surrounded with sheet piling to prevent lateral escape, and in the soil thus enclosed a sufficient number of piles were driven to impart the necessary consolidation by compression. If piles could be drawn and the spaces left by them filled with concrete this should always be done.

Mr. Sutclif

Mr. G. W. Sutcliffe observed that the time during which the experiments mentioned in the Paper had been continued was not given, but it was a most important element, especially in experiments on a small scale. All materials when damp would remain in a vertical position unsupported for a short time, the height of vertical face varying with the character of the material; obviously, within the limit of height of possible vertical face no active pressure against a wall could be expected until by the access of air, weather, &c., a change had taken place. Time would probably be found to be a more important element when the material was wet than when dry, but assuming sufficient time to be allowed the results would be more constant.

Coulomb's theory applied only to cases of purely frictional action without any adhesion or tenacity to influence the result; every case in which sidelong ground was formed into steps illustrated the advantages which were found to be practically available by paying attention to the tenacity of earth. The greatest possible height of vertical face appeared to furnish the best available index as to the effect of tenacity in influencing the result, being just sufficient to successfully resist the action of gravity in the particular case, and in other cases to vary directly as the height; in a greater or less degree a similar action obtained in every case in which the ultimate angle of repose was not assumed at once.

The Author appeared to have had most trouble with silty matter, in this agreeing with the experience of all engineers, and also where water had free access, and where the mass of the backing might be assumed to be in a condition approximating to that of material exposed to the weather; the backing of dock walls was in most cases in a similar condition, and the pressure was probably very near that obtained by Coulomb's rule, compensated for the effect of tenacity. To ascertain the absolute pressure within close limits was impossible, but it was nevertheless desirable to

r. Sutcliffe. make the closest estimate, though not to place much reliance upon it.

Experiments on earth pressures were most reliable when the mass was exposed to the weather, and the loading was effected by means of water slowly passed in or out by a siphon arranged to trip when a movement occurred; the load might be ascertained either by weighing the vessel and contents or by gauging.

The Author's conclusion would probably be endorsed by nearly all engineers with reference to situations like those of the several works of the Metropolitan railway, which were comparatively well protected from the weather and access of water.

The failures of piling arrangements and of cofferdams, &c., appeared to show that in tidal work the foundations were not responsible for all accidents, and that in walls the active pressure was often as great as might be expected from the application of the ordinary rule.

Mr. Whitley. Mr. H. MICHELL WHITLEY observed that no mention had been made in the Paper of the late Mr. Robert Stephenson's type of retaining wall, of which the proportions were as followed:—Thickness at base = height ÷ 3; thickness at half height = height ÷ 4; curved batter, 2 inches to the foot. These dimensions were for walls built in snecked rubble. For brickwork 1 foot in thickness was sometimes taken off. He had constructed a large number of retaining walls of this kind, mainly in stiff boulder clay, which, although it would stand for some weeks with a vertical face in the summer months, during wet winter weather gave great trouble. As a proof of the force exerted by this clay when in a semi-fluid state, he would instance the abutment of a girder bridge 15 feet high and 5 feet thick, with three counterforts 4 feet square, which bulged fully 3 inches after its erection. The work was built during the worst weather of an exceptionally severe winter, the brickwork was green, and the cause was evidently the swelling of the clay behind from exposure to frost, the work being built tight to the excavation. In contrast to this was the lightest wall with which he was acquainted. This was vertical, about 70 feet long, 14 feet high, and 18 inches thick, built of Portland cement concrete. After standing for a fortnight it was backed up with heavy clay, and showed no signs of failure; it was, however, noteworthy that a portion of this wall built in brickwork fell when backed up, showing the value of cement.

As bearing out the Author's views, he thought it might be interesting to mention the dry walls supporting the refuse heaps of the North Cornwall slate quarries, where the roads often passed between dry slate retaining walls sometimes nearly 25 feet high of the lightest construction. Mr. Whitl

No two types of wall could differ more than Mr. Brunel's and Mr. Stephenson's. He preferred the straight batter of the former to the curved one of the latter, in which the upper 6 feet were practically vertical, and he found that unless great care was exercised in the backing, the wall was liable to draw forward a few inches at the top, necessitating the taking down of some feet of the upper portion. The straight batter he also found much easier to build, and a crippled wall was less likely to occur. In the former wall counterforts were used; in the latter none. He considered these to be of great use in holding back the wall from the friction of the earth against their sides; and the walls constructed by Colonel Michon, of which mention had been made, appeared to show their value. In all cases where a wall gave way and had to be rebuilt, he inserted counterforts; and no single instance of failure where they were used had occurred, care being of course taken to bond them well into the body of the work.

In under-bridges with wing walls at right angles to the centre line of railway he thought it not desirable to insert counterforts where there was any chance of a slip in the bank taking place, as if one should occur close to the bridge it would most probably fracture the wing wall, whilst there was not so much liability of this taking place in a wall with a plain back.

With regard to the "sailing courses" in Mr. Brunel's wall, he had always considered them useful in taking up the pressure of the earth if the wall was properly backed up. The failures of walls of which he had had experience were invariably the result of bad backing, and water behind the wall, combined with brickwork in a green state; and he would urge the importance of thorough drainage, plenty of weepholes, and careful backing up, combined with the use of Aberthaw or blue lias lime in cases where cement was too costly, which it would be in the majority of instances of the wing walls of ordinary railway bridges.

Mr. J. EVELYN WILLIAMS stated that the portion of the Paper relating to dock walls was peculiarly interesting to him, as he had acquired much practical experience in the construction of several of those referred to. He was of opinion, however, that, in the case of dock walls, the theory of the lateral pressure of earthwork was of little value to the engineer compared with that knowledge, acquired by experience, which enabled him to judge of the general nature and supporting power of the strata when laid bare for inspection. Many failures in connection with Mr. Willia

r. Williams. dock walls would, in his opinion, be avoided if the needless expenditure incurred in the superstructure, in stone dressing and dowelling, were utilized in increasing the number of piles, or the thickness of the concrete in the foundation.

Mr. Baldry. Mr. J. D. **Baldry** mentioned two instances of walls of considerable depth, designed by the late Mr. Brunel, which might serve as further illustrations of that engineer's practice. These walls were built on the Oxford, Worcester, and Wolverhampton railway, the works of which were commenced by Mr. Brunel in the early days of railway construction, and were finished by Mr. Fowler, Past-President Inst. C.E., about 1855. The first example was one of the wing walls of the Hoo brook viaduct, near Kidderminster, and was of considerable height (Fig. 48). The counterforts were about 6 feet thick and 12 feet apart from centre to centre. The backing was of marl. One of the walls failed partially, but was rebuilt of the same dimensions and afterwards stood. The batter was 1 in 5. The other wall (Fig. 49) was much stouter, but still within the thickness in common use among engineers under the same conditions. It was one of the wing walls of the Mickleton tunnel entrance, and had stood very well. There were no counterforts in this case, but the wall was curved.

Fig. 48.

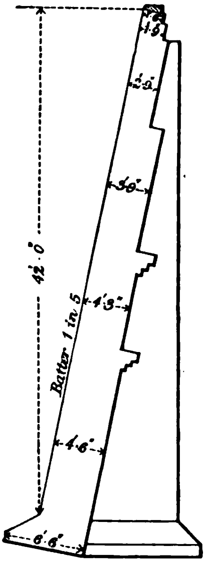
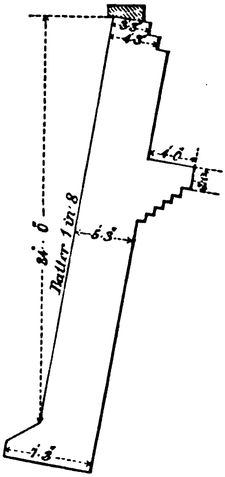


Fig. 49.



Scale, 16 feet = 1 inch.

Mr. Baldr

The material supported, blue lias clay, was very treacherous, and would not stand at a less slope than 3 to 1; indeed, in the cutting north of the tunnel, a slip of a serious kind occurred at that slope, which stopped the opening of a portion of the line for months, and an enormous quantity of stuff had to be removed. Having joined the staff of Mr. Fowler in 1852, direct from the Great Northern railway, which was emphatically a substantial school, the apparent slightness of the walls designed by Mr. Brunel surprised him, but he had known thicker walls to fail. He believed the works of the Birmingham, Dudley, and Wolverhampton railway, which were designed by Mr. Brunel at a later period, were generally stronger than those of the Oxford, Worcester, and Wolverhampton railway, and showed a disposition towards a larger factor of safety. The sailing courses, referred to by Mr. Lewis in the course of the discussion, were very pronounced in one of the two examples alluded to. Without disputing the obvious proposition that, by adding to the weight the resistance to overturn was increased, he had noticed that, owing to the settlement of the earth, cavities were formed below the sailing courses, however well the stuff was filled in and rammed, and he did not think this practice was a thing to be copied. Although Mr. Brunel made retaining walls much lighter than other engineers of his time, and had a type which formed the basis of his practice, yet exceptional ground was dealt with exceptionally, and that type was varied in many ways.

Mr. Baker

Mr. B. Baker, in reply to the correspondence, remarked that he had every reason to be satisfied with the discussion elicited by the Paper. He had charged both mathematicians and practical men with an indifference to the present unsatisfactory state of knowledge concerning the Actual Lateral Pressure of Earthwork, in terms which had provoked a reply from men of the highest eminence in each department. The communications from Mr. Flamant and Professors Boussinesq and Gaudard were in his opinion of exceptional value and interest. He must protest, however, against the charge implied against him of a contempt for theory. His habit of thought and mode of working were entirely opposed to such a feeling, and, indeed, in his opinion, an engineer who did not attempt to classify his practical data with the ultimate aim of elucidating a satisfactory theory was wilfully playing the part of a blind man. An engineer, however, must not be content with merely seeing a thing, but must approach it and handle it; and he thought that if theorists had to do the same they would often find that things were vastly different to what they appeared at first

Mr. Baker. glance, or from a more remote distance. He had said that "with little exception" the literature on the subject was "misleading and disappointing." He was glad to class Professor Boussinesq's communication amongst the exceptions, but it would be a sufficient justification for the charge in the opinion of most English engineers that even Professor Rankine's able and comparatively recent contribution was, according to Professor Boussinesq and Mr. Flamant, clearly liable to be characterised as "misleading and disappointing." Thus, Professor Boussinesq observed that Professor Rankine, in his formula, had made a supposition which "never was realised," and Mr. Flamant and Professor Boussinesq respectively pointed out that although for one particular angle of friction Rankine's theory gave the lateral pressure right in amount, in that and in most instances it was wholly wrong in direction. The numerical examples further showed that students might choose between the limits of one-fourth and one-sixth of the height for the theoretical minimum thickness of a given retaining wall according as they elected to be guided by Professor Rankine or by Professor Boussinesq. It was facts of this kind which, in his opinion, justified the statements that the bulk of existent literature on the subject could only be regarded as "a provisional approximation to the truth pending the acquirement of the necessary data" (page 141), and that "one authority after another has simply evaded the task of experimental investigation by assuming that some of the elements affecting the stability of earthwork are so uncertain in their operation as to justify their rejection, and have so relieved themselves from further trouble" (page 140). Professor Boussinesq had included one of the elements rejected by Professor Rankine, and so had obtained theoretical results much more nearly according with those obtained with the experimental walls and pressure boards referred to in the Paper. He had not attempted, however, to deal with the many other complicating elements which could not be similarly ignored by engineers when carrying out works in soil of varied quality and of different degrees of cohesiveness; and consequently the practical constructor had to fall back as before upon actual experience to inform him as to the proper thickness for a given retaining wall. This fact did not lessen in the smallest degree the value of the results so far obtained by theorists, though it should teach the student to be cautious in the application of theoretical results to practice. An engineer was indeed a student all his life so far as the practical construction of retaining walls and of the timbering of tunnels and trenches were concerned.

Much useful work had been done for the Institution by Professor

Mr. Baker.

Gaudard, and his criticisms were always worthy of careful consideration, and if Mr. Baker differed from them the difference was more apparent than real. Attention had been directed by Professor Gaudard to the complicating question of foundations, and he himself had referred to this matter and pointed out that his experiences with timbered trenches were free from the complication of sinking and sliding foundations. The problem, to the solution of which mathematicians had addressed themselves, was, as truly stated by Professor Gaudard, the determination of the thrust of homogeneous and friable earth reduced by rain or otherwise to a form unstable and dangerous. He, on the other hand, whilst equally interested with mathematicians in the solution of that problem, had taken as the subject of his Paper the far wider question of the Actual Lateral Pressure of Earthwork. Sooner or later, most soils exposed in slopes would lose their cohesion from the action of rain and frost; but was it right to assume that the same would occur when the soil was protected from the weather by a thick retaining wall? In temporary works, such as the timbering of trenches and tunnels, the natural cohesion of the soil was immensely relied upon, and the adoption of the mathematician's hypothesis would lead to the useless expenditure of thousands of pounds in every great work. The angle of repose, Professor Gaudard observed, was taken by mathematicians as a function of the physical property of the soil easily measured experimentally. No doubt the measurement of a slope was an easier experiment than measuring the direct lateral pressure; but was the former experiment an efficient substitute for the latter? The angle of repose was a rather vague measurement after all. In tipping a bank the material had a certain initial velocity, and the momentum induced a flatter slope of repose than would obtain with the same material in a cutting. Nothing was commoner in practice than to specify the slopes of cuttings at 1 to 1, and the slopes of embankments formed from the soil removed from the cuttings at 1½ to 1. Even in cuttings, where of course the question of tipping did not arise, a slip generally began by the detachment of a comparatively insignificant portion of earthwork, which in its descent dislodged by its momentum other portions, but which itself might have been held up by a trifling amount of lateral support. In practice he was convinced that the work which timbering had to do was more generally the provision of that trifling amount of support to prevent an initial slip than the resistance of the full theoretical thrust. He doubted much whether the angle of repose, as ordinarily understood, was a function of the physical property of the

Mr. Baker. material from which the actual thrust could be deduced. He thought it far preferable that theory should be used to elucidate experimental results than to predict results, and engineers were constantly having this enforced upon their attention.

As a case in point he might mention that some years ago Mr. Westinghouse told him that he had found, in experiments with his continuous brakes, that a considerably greater pressure was required to skid a wheel than to hold it when skidded; and Mr. Baker had not unnaturally remarked that this was to be explained on theoretical grounds, as it was probably mainly due to the necessary destruction of the momentum of the revolving wheels. However, when exact and exhaustive experiments were carried out with a special apparatus, it was found that this was not so at all. No theoretical deduction from the laws of dynamics and from previous experiments on static and dynamic friction would have led an engineer to conclude that some six to eight times the pressure on the brake blocks would be required to skid a wheel than to hold it when once skidded, or to predict the result obtained by Captain Galton in one of his experiments, where, with 24,000 lbs. pressure upon the brake blocks, the experimental van ran rather more than twice the distance before coming to rest than it did with the reduced pressure of 17,500 lbs. upon the brakes. He did not think that an engineer would be "too contemptuous of mathematics," or reflect at all upon the value of Newton's researches, if he maintained that, unaided by direct experiments and guided only by indirect experiments on frictional resistance and theoretical deductions from the laws of dynamics, the result, as regarded the practical question of continuous brakes, would be "misleading and disappointing."

On analogous grounds he protested against any theoretical deductions from angles of repose being accepted as the practical equivalent of a direct measure of the lateral pressure of earthwork, although he appraised at the highest value the able investigations of Professor Boussinesq and others like him. Professor Gaudard would appear to doubt his statement that an experienced engineer might at once sketch as suitable a cross-section for a given wall as he could hope to arrive at after any amount of investigation, though he would probably admit that a recruiting sergeant would estimate a man's weight to a couple of pounds, though he could deal with it only as a whole, and not with the several elements of bone, blood, and muscle which combined to form that whole. Similarly the practical engineer, after an inspection of the ground, could sketch a wall of the required stability, though he might be puzzled to state the slope of repose, the coefficients of friction against the back of the

Mr. Bake

wall and on the foundation, and the degree of fluidity or cohesion of soil in any particular case. Whilst cordially agreeing with Professor Gaudard that the present Paper could be considered "only as an instalment, relating to abnormal, heterogeneous cases, outside the scope of any general law," he claimed that those were just the cases that an engineer had to deal with, and that he was justified, therefore, in attempting to show, by direct and indirect experiments, that the actual lateral thrust of good earthwork was far less than ordinary text books would lead a student to infer; and secondly, by practical examples of dock and other walls, that in actual works a large factor of safety was required in walls, as in other works, to cover contingencies of various kinds and degrees.

An experience at the Bute docks had been stated by Mr. Hawkshaw which had frequently occurred elsewhere, and there was no doubt as to the correctness of the inference that dock walls should commonly be looked upon as heavily surcharged walls. Mr. Livesey had given an interesting example of a lightly proportioned wall, or rather well lining, the satisfactory stability of which, in a green state, confirmed the general conclusions as to the very light lateral thrust of good soil when first cut into. The main ventilating shafts of the Kilsby tunnel were 66 feet in external diameter, 132 feet in height, and 3 feet thick, whilst the tunnel itself was 2 feet 3 inches thick, though the internal width was but 24 feet. Mr. Meÿer had directed attention to cases of walls with mud backing. Mr. Baker thought in the majority of such cases the wall received support from the water in the dock; but if it were not so, or if the water in the dock were liable to be drawn off, he thought the wall would follow it in a few days or weeks, as the case might be, unless proportioned to withstand the pressure of the mud as a fluid of high specific gravity. Mr. Prince had been "much surprised to find the profession accepting the principle that piles in a foundation were for the purpose of carrying weight," as he had been "taught, and still maintained, that the object to be kept in view was the consolidation of the strata or soil on which the structure was to rest." Mr. Baker was rather surprised at Mr. Prince's surprise, as he held with Mr. Bramwell, that by no amount of sticking in of pins could it be reasonably expected to consolidate a pat of butter. Assuming the foundation to be first surrounded with sheet piling, as recommended by Mr. Prince, then experience had amply proved that if the soil were clay the quantity displaced towards the surface would be practically equal to the cubic measurement of the piles driven, whilst if the soil were sand the piles would generally refuse to be driven at all. With silt and some other soils compression no doubt

Mr. Baker. occurred, and the skin friction on the pile resultant therefrom would then be the chief element of resistance. Mr. Sutcliffe had observed that the time during which the experiments mentioned in the Paper had been continued was not given, but with reference to this he would remark that he had selected absolutely clean and "greasy" ballast and coal for his pressure board experiments, because clearly no lapse of time could increase the degree of cleanness and greasiness or augment the lateral thrust. Mr. Whitley had communicated some interesting facts; and he was glad to find an experienced dock constructor like Mr. Williams agree with the general conclusions expressed in the Paper as to the supremacy of practical over theoretical conditions in all such cases.

NOTE BY THE AUTHOR.

Since the above was written the Author has had occasion to inquire into a case of "actual lateral thrust" involving very serious if not fatal injury to ten persons. On the 27th of June 1881 a brick fence wall, about 50 feet long, 10 feet 6 inches high and 14 inches thick, fell from the lateral pressure of a large mass of coal which the occupiers of an adjoining wharf had been in the habit for some years past of piling against it to a mean effective height of rather more than 9 feet. The weight of the coal being 50 lbs. per cubic foot, and the slope of repose 1½ to 1, the "equivalent fluid pressure," according to the table on page 144, would be 14·35 lbs. per cubic foot. The Author's experiments with a pressure board (Ex. 21, p. 155) indicated, however, that the Actual Lateral Pressure would be more nearly that corresponding to a fluid of 6 lbs. than 14·35 lbs. per cubic foot, and it was easy to ascertain if this were so. When the wall fell each brick cleanly separated itself from its neighbours, and there was other evidence to show that the mortar had perished and had no tenacity at the joints, owing partly no doubt to the bulging and shaking of the wall from the constant tipping of coal against it. Under these circumstances the maximum moment of stability of the wall per lineal foot would be 1,250 lbs. × 7 inches ÷ 12 inches = 730 foot-pounds. Dividing by $\frac{h^3}{6} = \frac{9^3}{6}$, the fluid pressure required to overturn the wall would be found to be 6 lbs. per cubic foot, or exactly that which the Author's experiments would have led him to predict, and considerably less than one-half the 14·35 lbs. indicated by the ordinary or false theory as the equivalent of the lateral thrust of the coal. Applying Rankine's formula[1] for upright rectangular walls:—

$$\frac{t}{x} = \tan\left(\frac{90^\circ - \phi}{2}\right)\sqrt{\frac{w^1}{6\,q\,w}}$$

and giving q its maximum value of 0·5, the minimum thickness of wall would be found to be 1·827 foot, whereas the actual thickness was 1·166 foot. The squares of these thicknesses hold of course the same ratio to each other as the

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[1] "Civil Engineering," Art. 266.

14·35 lbs. calculated and the 6 lbs. experimental "equivalent fluid pressures." As illustrative of the Author's statement that labourers and others in stacking materials did not trouble about factors of safety, it was interesting to note that, notwithstanding the accident referred to, another length of wall on the same wharf was still subject to a lateral thrust theoretically exceeding its powers of resistance by at least 100 per cent. Mr. B

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12 April, 1881.

JAMES ABERNETHY, F.R.S.E., President,
in the Chair.

The discussion upon the Paper on "The Actual Lateral Pressure of Earthwork," by Mr. Benjamin Baker, occupied the whole evening.

In accordance with the notice on the card of the meetings, it was resolved to adjourn for a fortnight, in order to avoid holding a meeting on the evening of Easter Tuesday, April 19th.

SECT. II.—OTHER SELECTED PAPERS.

(*Paper No. 1682.*)

"The Empress Bridge over the Sutlej."

By JAMES RICHARD BELL, M. Inst. C.E.

WITH spans of 264 feet, and foundations more than 100 feet below low water, the Empress bridge has been carried across the combined Sutlej and Beas rivers with less than a mile of length, and so presents a decided advance in Indian engineering practice (Plate 2).

In earlier dealings with the Punjab rivers, the Scinde, Punjab, and Delhi Railway Company had bridged the Sutlej and Beas, using as piers single wells 12 feet in diameter and only 40 feet deep; and when these works failed, in spite of lavish stone protection, the Punjab Northern State Railway adopted a standard type of pier on three wells sunk 70 feet below low-water level.

In Mr. Lambert's communication to the Institution on the Alexandra bridge,[1] it would seem that on the Punjab Northern Railway stone protection for the piers was an after-thought, and that, from neglecting this precaution, three piers, though sunk 70 feet, were overturned by a flood in the Chenab. It was therefore determined to go down 100 feet, and to use stone protection as well on the still more treacherous Sutlej.

Each pier of the Empress bridge consists of three wells, each 18 feet 9 inches[2] in diameter, pitched in line and gathered at the top into a parallelogram, with rounded ends (Plate 3, Figs. 1, 2, 3, 4, and 5). This is effected by corbelling out the wells to a square form, till they almost touch each other just below low water. On this parallelogram, which is 63 feet long by 19 feet wide, rests a plinth 52 feet by 15½ feet, also with rounded ends, and on this stands a pier of similar shape, 42 feet by 14 feet. The line of the pier and its three wells is of course at right angles to the centre line of the bridge, and parallel to the assumed axis of the stream. Such an assumption, however, as that the stream is even approximately constant to a fixed axis is unwarrantable. The channel of the river actually ran parallel to the bridge during the season 1876-7. Apparently, too, the lost piers of the Chenab bridge were similarly taken in flank.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. liv., p. 71.

[2] In practice the use of old bricks made the diameter of the wells 19 feet.—J. R. B.

In this respect the single wells on the Scinde, Punjab, and Delhi Railway were undoubtedly correct in principle, as presenting an equally good face to any direction of channel. A serious hindrance to sound and economical practice has arisen from a belief that a depth of 40 feet was sufficient. If this depth had been multiplied by 2 or 2½, and the diameter of the piers and the length of the spans had been increased in due proportion, a problem would have been solved which still awaits solution. It should, however, be stated that considerations partly strategic, partly commercial, involved the adoption of sites on the Scinde, Punjab, and Delhi Railway, which on purely engineering considerations should have been avoided, whatever the design of pier.

A circular well, 32 feet in diameter, or an oval of 32 feet by 30 feet would have been safer, would have required only two-thirds of the masonry now used, and with the advantage of greater room for working would have been sunk for half the cost of three 19-feet wells. Each pier of the Empress bridge is protected from scour by an average of 75,000 cubic feet of loose stone. When laid in on an exposed sand-bank, for the protection of a pier foundation not yet fully sunk, the stone is disposed in an annular mass at some distance from the wells, in order that when undermined by scour it may so fall as not to hinder subsequent well-sinking operations. The whole object of the stone is that, when attacked by the current, it should sink and automatically pitch the slopes of a submerged cone of earth and sand which surrounds and upholds the masonry pier. There is no intention of maintaining the condition of the bed when its depth is shallow; on the contrary, the protection is designed to allow and even to facilitate deepening by scour at all points except in the vicinity of the pier. It is the Author's practice to add fresh stone whenever the slipping of the slopes of the cone exposes more than a third of the submerged pier in floods.

One of many objections to small span bridges for a river of this class is that these cones meet at much less than the natural depth of the flood channel and form a sunken weir, which backs up the stream and creates a rapid. Such a rapid excavates a dangerous pit just below, and from the fact that in recent mishaps to the Scinde, Punjab, and Delhi railway bridges the pier-heads fell up stream, it seems probable that the footings had slipped down into the pits described. It is certain, whatever be the action of the pit, that a sunken weir upholding a river must increase the spills above, and must *pro tanto* increase the tendency of the river to breach the approaches, and to accept some such unobstructed breach as its new course.

The abutments of the Empress bridge are piers surrounded with masses of stone, which extend across one span and enclose the next pier towards the river. Towards the land the stone is piled up behind the pier, and forms a rude wing wall to retain the railway embankment. Forming, as it should do, a continuation of the breakwater for protecting the river bank, the landward part of this device of Mr. Molesworth is admirable, provided a puddled bank in rear of the masonry is used to stop percolation, which might else destroy the embankments. But the projection from the abutment of a massive stone groyne, reaching to the first pier, is at best a costly means of keeping the deep channel away from the abutment; and from its tendency to deflect the stream, and so to induce a cutting bend against the river bank, the plan has been found to exaggerate, if it does not provoke, the evil intended to be remedied. Should these groynes ultimately sink, as is their tendency in the Ravi and Chenab, it will be well not to make them up for their whole length.

The outer and inner diameters of the wells are respectively 19 feet and 8 feet 3 inches. The curbs are of deodar timber, 3 feet wide and 3 feet 6 inches deep, strongly bolted and hooped by a $\frac{3}{4}$-inch cutter bar. The lower brickwork corbels inwards, from 3 feet at the curb to 5 feet 4$\frac{1}{2}$ inches at 12 feet above. Except at the corbels, the well and its shaft are cylindrical. From the curb twelve bolts of 1$\frac{5}{8}$ inch diameter over the thread are carried up to the top of the masonry in lengths of from 15 to 18 feet. The joints are made with bottle nuts screwed down on washer-plates, which form in the aggregate polygonal bond rings. As an example of the importance of minor details, it may be mentioned that by reducing the shanks of all the bolts to the diameter of the root of their threads, a saving of more than £3,000 on the whole bridge might have been effected.

The depth of the excavation below the curbs, when sinking is completed, varies from 2 feet in sand to nearly 15 feet in clay in the centre of each well. This hole, and the lower 20 feet of the shaft, is filled with hydraulic concrete, succeeded by fine sand, and closed with a plug of concrete 9 feet thick and of masonry 3 feet thick. Thus the depth of foundation varies from 105 to 118 feet, and averages 110 feet. The wells and their corbel tables are completely hidden, even at low water, and only the plinths appear. When submerged by floods of over 3 feet 6 inches, the plinth starling is perhaps a danger for native boats. Had it been carried up to the top it would have afforded room for a second line of girders, but this will probably never be required.

Owing to the presence of various salts in the soil and water all bricks were burnt till their surfaces were partially vitrified. No broken bricks were used in the permanent masonry, and no mortar which had been wetted for more than twenty-four hours. The mortar was composed of 1 measure of fat lime, 2 measures of fine brick-dust, and 2 measures of hydraulic lime. The whole was ground dry in pans. In fineness and colour this mixture closely resembled Portland cement, and, costing about 1*s.* 4*d.* a cubic foot, was not much cheaper than, nor was it inferior to, cement after being stored some time in India. For building the false steining, mortar spoilt by rain, diluted with twice its bulk of micaceous sand, was used, and such was the tenacity of even this diluted mortar, that in taking the false work down it was impossible to detach a whole brick. The false steining was added to keep the mouth of the well above water up to the end of the working season.

The tops of the piers are alternately higher for the fixed, and lower for the roller, ends of the girders. Below the seats of the girder the pier is finished with an ashlar course 2 feet thick, and each bed consists of one stone 7 feet long in the length of the pier, and three stones in its width of 14 feet. Most of these stones came by rail from Agra, 800 miles distant. Each set of three bed-stones is held together by a tie-plate, 15 feet by 5 feet by $\frac{3}{4}$ inch, laid across the pier and bedded on the ashlar. The two plates of one pier are connected by inverted 5-inch angle-irons, bedded against the face of the pier. After setting the girders, their holding-down bolts were fixed in holes drilled in the tie-plate and the bed-stones, through the holes in the bed-plates. The shanks of the bolts are cylindrical, and their surfaces are barbed by being cut like a rasp, so as to require driving into the hole. The thread broke in an experimental attempt to draw such a 1½-inch bolt out of the stone.

The girders,[1] which are of the double N or Murphy-Whipple type, are 257 feet long between the centres of the bearing pins, and weigh about 405 tons, including a complete wrought-iron buckled-plate floor, designed, at the instance of Sir Andrew Clarke, K.C.M.G., C.B., Assoc. Inst. C.E., to carry heavy siege guns on their own wheels. The bridge was so employed by the Kandahar force in the late Afghan war, and guns, camels, cavalry and elephants used it as a road bridge soon after opening. The first elephant that stepped on the bridge tried to shake the end ties before he would adventure further. The weight of the girders will not appear excessive when it is considered that the floor forms a fourth part of the total, and that the mere dead weight increases the strength and weight required in the other parts of the structure.

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[1] *Vide* "Engineering," vol. xxvi., pp. 454, 489.

In building, the masons were restricted to a height of 5 feet vertical per day on wells, and of 2½ feet on superstructures. The first setting on the wells was 15 feet high besides the curb; the second, 18 feet; the third, 36 feet; and the last, including the corbelling and the false steining, 41 feet, or 110 feet altogether. The masonry all round cost Rs. 43 per 100 cubic feet, or about 8¼*d.* per cubic foot. The work was pointed throughout; the wells were not plastered, and no delay was allowed for the masonry of the well to set before loading it with rails. The masons' work, including fixing and dismantling scaffolds, occupied thirty-five working days for each well.

The lower loading rails were laid across baulks 24 inches square, with an 8-feet gangway between for the passage of trollies (Figs. 1 and 2). On the top of the rails came the sinking gear and men. The emptying and setting of the tools in use was done in the gangway, which saved several feet of hoist. The crossed stacks of 24-feet rails in a centre well necessarily fouled the flank loads and occasioned considerable delay in the first season, till the lozenge-shaped plan (Fig. 2) was introduced. As a rule the first setting of masonry required no load for sinking; the second took from 150 to 200 tons; the third, from 300 to 400 tons, and the last from 450 to 600 tons; while in refractory cases 800 and even 1,000 tons were used. With wells standing 35 and 40 feet above ground, and stacks of rails reaching 15 or 20 feet more, the stacking process was slow and scarcely averaged 30 tons a day on any one well. The work could not be done at night, and as a rule it occupied thirty-five working days for each well. Owing to the risk of crippling the rails the unloading of the second and third settings occupied twelve days. To this must be added eight days for fixing and dismantling the sinking plant, thirty-five days for loading, and thirty-five days for building, together ninety working days, out of a season lasting at most two hundred and ninety days.

The loading occupied about 4½ feet in height per 100 tons against 6½ feet of masonry; and it must be admitted that, notwithstanding its slightly greater stability, the use of rails in the second and third settings was a mistake. By substituting the same weight of masonry, thirty working days might have been saved with many obvious contingent advantages, and the only drawback would have been the cost of a few extra screwed ends and bottle nuts for using shorter lengths of well-bolts. With a single large well, surmounted by a pier of the same shape, a still greater saving in this item may be looked for.

At one time £125,000 worth of permanent way for about 150 miles of road, mostly of 40-lb. and 36-lb. sections, were locked up in the Sutlej works. The cost of freight of rails, carriage between one well and another, ferryage to and from wells in the stream, loss, breakage, and, above all, the frequent and hurried clearance of the river bed when freshets were threatened, have not been kept distinct from other well-sinking charges. The Author estimates that, first and last, the weighting of the wells cost nearly half the total well-sinking charges, or about £6 per lineal foot of well.

In a season of two hundred and ninety days, forty-one Sundays were devoted to washing out boilers and repairs necessary for the week's work; nine days at least were lost owing to important native holidays; perhaps ten days more may be credited to partial holidays, and fifteen days to breakdowns of machinery, floods, storms, &c. At least twenty-five days additional may on the average be set down to centre wells standing while the flank wells gained the requisite lead, and to flank wells waiting for loading rails to be transferred from others. Thus in all on one hundred days out of two hundred and ninety, no work was done; while of the remaining one hundred and ninety days, at least ninety were required for work preparatory to sinking, such as building, loading, &c., irrespective of the time occupied in preparing the ground for operations. Thus no more than one hundred clear days were available for actual sinking work in one season; and in all cases at the Sutlej the work of unloading the final setting was carried over to the second season.

The entire work on the foundations occupied three complete seasons, in the first of which the average progress on eighteen new wells was 62½ feet, 81½ in sand and only 43½ in clay. In the second season thirteen old wells were finished and three more advanced, while twenty-one new wells made an average of 89 feet. In the third season seventeen old wells were finished, and also the remaining twelve new ones, which were all in clay. This brought up the average season's progress to 103½ feet.

In sand, Bull's dredgers alone were used, and for the most part these were of 10 and of 12 cubic feet capacity. In clay, which in ten of the seventeen piers was met with about 30 feet below the surface, and of a tenacity for which the trial wells left the engineers unprepared, the first season's work was done wholly by divers, who only managed to sink the wells about 15 feet into the clay.

By the beginning of the second season Mr. R. Gatmell, the foreman well-sinker, had perfected his clay-excavators[1] (Plate 3, Figs. 6, 7, 8, 9, and 10) and by these implements the work was finished in a most satisfactory way; nay, after discounting the fact that every new tool works best under its inventor's eye, it is certain that no existing appliances of that day could be compared with these tools for efficiency. Though Bull's dredgers have often been described,[2] it may still be well to point out that the downward cutting of its pans is the resultant of the upward jerking of the arms acting against the inertia of the machine. The larger and, *pro tanto*, the heavier the dredger, the harder the material it will cut; and though it did not occur to Mr. Gatmell that a Bull's dredger with a heavily loaded fulcrum would cut clay, he appreciated the necessity of an anvil. His appliance consists of two "jhams," or large shovel blades, hinged back to back at the foot of a heavy ram made of rails. Arms project outwards at right angles from the blades, and are jerked upwards by sling chains connected to the hoisting chain, and under the heavy reaction of the ram, these blades cut into the stiffest clay; while as the jerking goes on the sling chains ultimately turn the blades outwards under the two masses which they have cut. The rams used are of three lengths, 5 feet, 7 feet, and 9 feet, and proportional weights; the blades are of one size, and are interchangeable, or they can be replaced by skeleton angle-iron prongs for breaking-up conglomerated nodular limestone, of which thin beds were sometimes met with. The longer rams, though more powerful, are liable to fall over in the hole, and in using them one blade sometimes comes up empty. In a later design Mr. Gatmell adopted a short ram to which weights can be added as desired; also scoops capable of holding sand and semi-fluid débris.

The side-cutting tool, for undermining the curb, is one-half of the centre excavator with a 24-feet rail for a ram (Fig. 8). The rail is slung to an independent rope, which hangs it at an angle that will undercut the curb. By moving the rope, the blade is brought to bear at fresh points of the circumference of the well. The defect of this instrument is its liability to cut isolated grips, leaving walls between, which have either to be cut away by divers, or undermined by greatly deepening the centre hole. Where the wells are earth-bound, and still more when they are hung up and jammed with stone protection, this deepening of the sump is liable to induce the somewhat dangerous phenomenon called "belching."

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xlviii., p. 103.

[2] *Ibid.*, vol. xxxix., p. 213.

In sand the excavation was only carried on till it sounded 2 feet below the curb, but in clay it was often necessary to go down 12 or 15 feet. In either case, when the excavation was judged sufficient, the water in the shaft was rapidly drawn out by large leathern buckets, two of 15 cubic feet capacity being worked by steam-hoists, and four of 6 cubic feet by gangs of labourers.

Lowering the water in the shaft increases the virtual weight of so much of the brickwork by the value of its displacement, and if the lowering is effected rapidly, this accession of weight is thrown on the curb with a certain momentum, and has a powerful tendency to cause the whole well to drop. At the same time the influx of fresh water from below scours the sand away rapidly from under the curb, and even in hard strata it brings in the silt lying in the crevices of the clay, which it thus tends to break up. Above all, as the influx of water below is mainly supplied by percolation along the outer surface of the well, this so lubricates the masonry as greatly to facilitate its descent. "Runs" of 6 feet at a time are common, and a run of 13 feet has been recorded in a well in sand, but this is very exceptional.

At the Sutlej it was an uncommon occurrence for a well to follow the excavation without running. The silt, notwithstanding its hardness, was so fissured by what must have been sun-cracks in the land ages ago, that it was seldom possible to run any well dry. In fact, no one well was kept dry for hand-sinking more than twenty-four hours. The water-level could generally be reduced 25 feet by running. The run lasted about two hours, and terminated by the well being completely silted up to the then water-level. In an inadequately loaded well this "blowing" of sand or silt is not accompanied by corresponding sinkage.

On starting to dredge after a "blow" the greatest care is needed to prevent the tool getting buried. At first Bull's dredger has to be sent down closed, and is filled over its lip like a bucket. As the silt sets the dredger is used open, but not jerked, and so on gradually as the hardness of the soil warrants. If buried at any great depth, a lost tool often takes fifteen or twenty days to recover; and if the depth be over 100 feet, the recovery of a lost tool by divers is a most hazardous undertaking.

As stated above, the clay-wells of the first season were with difficulty sunk to 43½ feet for want of automatic tools, and as the deep stream threatened to attack these wells with the whole weight of the floods, they had to be copiously protected with stone. Most fortunately they stood, although the channel between them was cut down to below the curbs. Due care was not, and probably, under the circumstances, could not have been, exercised to keep a space between the stone and the masonry, and the wells became so hampered by the stone, that the most heavily protected pier took two more seasons to sink, and carried some stones down with it to below the 110-feet line. Indeed, the attempt to sink the last 3½ feet of the centre well of this pier was ultimately abandoned in favour of under-pinning it with concrete. With 1,000 tons of rails, in addition to its own 1,700 tons of masonry, and a 15-feet hole beneath, this well gained an additional depth of only 7 feet in two months' working, and finally ceased moving. It was in these three piers in the first season that the "belching" was most dangerous. It appears that the advanced sump occasionally tapped a vein of quicksand under the clay, and that even without running the well, this sand sometimes escaped into the sump, leaving considerable areas of clay unsupported. Sooner or later the undermined area of clay went down suddenly, disturbing the surface of the ground, and squeezing a large volume of water and silt into the well with extraordinary violence. Instances have occurred of the water surging up through a well 15 feet above ground, washing off those men who failed to catch the "man-ropes," and pouring out in a considerable stream for hours together, while the in-rush of silt sometimes rose in the well-shaft to a height of 60 feet, and completely buried the tools.

The only serviceable method of keeping back the blow is water-pressure. It is, however, difficult to get the men to keep the wells surcharged with water, as the pressure hardens the bottom, and prevents the tools from biting. With any considerable surcharge, even pure sand is so indurated that nothing will penetrate it. The Author tried a rough modification of the apparatus used by Mr. Bradford Leslie, M. Inst. C.E., at the Gorai bridge, under conditions which necessitated a surcharge of 24 feet of water.[1] Under this head pure micaceous sand broke off cutters made of steel 1¼ inch square.

For straightening wells, which is impossible when they are sunk much beyond 50 feet, shores and chains were mostly used, coupled with excavating the ground outside the well. The chains were a failure, in the absence of Mr. Mallet's ingenious plan of loading rails on them in order to take up the slack as the well went down.[2] Another plan is to load the ground outside the well with a stack of heavy material. Where the curb is in the upper part of the clay stratum, the weight of such a stack will push the curb away, while in deep wells the top will go over. During the sinking of one pier from 90 to 96 feet, when the river had engulfed the stone protection along one side, the weight of stone on the other side pushed the three wells over 2 feet beyond the perpendicular. The action stopped when the stone was removed, and it is scarcely thought possible that the wells would have canted when they had penetrated more than 90 feet in the ground, had they not been at the same time sinking.

If well-sinking is to be carried much beyond 100 feet, improved means of picking up lost tackle must be devised. In 110 feet of sludge, helmet diving should never be attempted for more than twelve minutes at a time, and only then in the presence of an engineer and a medical officer. Judging from the greater depths attained in the open sea, it seems likely that the utter darkness of a narrow well aggravates the deleterious effects of air at high pressure. The best diver at the Sutlej was crippled for life by staying down fifteen minutes in a depth of 115 feet of sludge, and rather than risk another man to sling them, it was determined to bury the lost tools in the concrete.

The total cost of sinking a well was Rs. 153 per lineal foot, or nearly £40 per lineal foot on each pier, including £18 for weighting with rails.

The quickest work was with the piers of the last season, and the last pier was completed, together with the girders it supports, in a few days under twelve months. The stone-jammed pier was, including its spans, three years and three months in hand. Except for four hours in the heat of the day, and from midnight on Saturday to 6 P.M. on Sunday, the well-sinking work went on continuously in the season.

To strip 2,000 tons of rails and 10 feet of false steining from a pier when fully sunk, often took three months, where the pier was isolated in the water and not on a sand-bank. In such cases the plinth had often to be started 2 or 3 feet below the then level of water in the river, and for this purpose a somewhat novel coffer-dam was used. The dam consisted wholly of sheet piles formed of 10-feet sleepers, measuring 10 inches wide by 5 inches thick. The edges were rounded and hollowed, and there was a strip of felt at each joint. Instead of being driven into the stone protection, which was sometimes 12 or 15 feet below water, the sheet piles were simply clasped to the masonry by chains tightened by coupling screws, so that when the two gaps between the corbel tables of the wells were stopped up with concrete rammed into a strong sail-cloth bag, the whole dam was like an oblong tub with sleepers for staves, a masonry bottom, and chain hoops. The bottom joint between the staves and the masonry was caulked, and the joints of the dam were tightened by pairs of staves formed as counter-wedges. With piers in the sand-banks no dam of any sort was required.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxiv., p. 8.

[2] *Ibid.*, vol. liv., p. 68.

The neat work was set out with great exactness by measuring the distance between the centres of the piers with a piano wire. If allowance be made for changes of temperature, the length of a given wire is constant under the same tension. In the instrument used (Plate 3, Figs. 11 and 12) the temperature was compensated by adjusting the wire afresh from time to time on a standard base-line. The tension was that of a constant steelyard, and the distance was repeated with the most minute accuracy, by moving the knife-edges of the steelyard till the pull of the wire exactly balanced its bar. Though roughly made and adjusted by hand, the instrument showed a maximum discrepancy of only $\frac{3}{8}$ inch in three measurements of the $\frac{4}{5}$-mile length of the bridge. The working tension was about 20 tons to the square inch. In subsequently measuring the width of the Indus at Sukkur with the same appliance the versed sine under this tension was 3 feet in 1,000. The wire does not indicate the number of feet between its extremities; it merely repeats the distance to which it is set, and allows of this being remeasured on an accessible base. When first drawn across a span by a string, the twisting of the cord threw the wire into kinks, at which it snapped, but a native maistry stopped this action by lashing a walking-stick to the end of the wire, so as to act like the ball and lever of a coupling screw.

When the stone-jammed pier had its rails at last unloaded the walls were found to have canted so far that, to avoid building the pier askew, it had to be slewed over 20 inches. This error was divided out by increasing two spans by 10 inches each and diminishing two others. In the increased spans the bed-plates of the girders are 5 inches nearer the edge of the masonry than designed.

During the first, third, and fourth seasons that the main bridge was in hand, temporary pile bridges of about 1,000 feet in length were constructed in the dry season. The peculiar difficulty in these works lies in the fact that the friction of the fine sand will only allow a pile to be driven at most 15 or 16 feet, a depth utterly inadequate against the scour of freshets, which in shallow water sometimes deepens the channel 20 feet in one night. In deep water the scour is less, but long piles of a scantling to carry a railway train are difficult to procure in the Punjab, and more difficult to pitch in a rapid eddying stream. In a shallow bridge the bed can be protected as soon as the piles are in; but where stone costs 7½*d.* per cubic foot, brick cubes 4½*d.*, and sandbags 3½*d.* the protection is costly, and if it holds the bed too well it provokes an attack on the approaches.

The bridge of 1874–5 was completed in February, and was only upheld by lavish protection. That of 1876–7 was built during December; but its bank was breached in February, and it had to be lengthened 300 feet. The first bridge of 1877-8 was built in three weeks with one end in 35 feet depth of water. Protection was deferred till extra piles had been put in to strengthen the bridge for public traffic, and during the delay two-thirds of the structure were completely wrecked by a 3½-feet fresh. The next, the water being shallow, was reconstructed twice, and lasted only four months. Lastly, the pile-staging in two spans of the main bridge took three weeks each span to put up, one in 56 and one in 42 feet depth of water, with piles from 65 to 75 feet long. In a rapid stream the pitching of piles as long as the wells of previous Punjab bridges was a difficult business, but was greatly facilitated by the lower part of each pile being weighted with four rails fished to it by clamps, in order to increase its stiffness. Each bay was cross-braced diagonally under water by chains and screw-couplings. The four lines of longitudinal beams were wedged up endwise to the masonry of the piers, and a diagonal bracing of rails on the top converted the platform into a horizontal girder 250 feet long and 36 feet wide.

No sooner was the deeper of these stages built and protected at the bottom with 13-inch cubical bricks, strung in chaplets round the piles on ropes passed through central holes in the cubes, than the river rose 5 feet 6 inches up to the under side of the sills, while the hole at the foot of the submerged weir of cubes was deepened to more than 70 feet. Fortunately the girders erected on the sand-bank, and the preparations for diverting part of the river under these girders, admitted of the pressure on this deep stage being materially relieved by opening more spans for the water to flow through, and but for this relief the stage would have been overtopped. As it was, the officers in charge had an anxious time, and although the stage stood without a tremor, it was impossible to ascertain, by sounding in such a rapid current, whether the piles were being under-scoured or not. Thirty days after this flood the remaining stage had been built, and the girders over both spans were completed. These stages, and four temporary bridges, cost in all, for labour and materials, nearly £20,000.

The delivery of so much heavy ironwork (6,700 tons) at such a distance inland in so short a time, determined the Government of India to apportion the delivery of materials between the ports of Calcutta, 1,500 miles distant, Bombay, 1,800 miles, and Kurrachee, only 600 miles from the site of the bridge, but costing by river steamer as much as 1,100 miles by rail.

The ironwork arrived in irregular order, and two or more spans (in some cases by different makers) were under receipt at the same time. Under these circumstances the first thing was to separate the different spans, and to this end four unloading platforms were prepared. To facilitate moving the larger pieces, the platform was faced with greased rails, and had a considerable fall from the line on which the wagons arrived towards that on which the trollies removed the parts to the stage. The second point was to distribute the parts of a span into classes, with each class separately accessible to the trollies. This was effected by dividing the length of the platform into "skids" set apart for bottom booms, top booms, posts, ties, lower cross-girders, upper cross-girders, road trimmers, and lastly a skid for damaged pieces needing repairs.

By hand-shunting the wagons as they arrived to the proper skids, each piece was unloaded with the rest of its class, and it was then possible to ascertain what parts of the girders belonging to that platform might still be wanting. In this state any required class of parts could be loaded on the trollies, and by shunting these at a loop siding the pieces were placed in the order for ascending to the stages. This arrangement was simple and efficacious in working. A train seldom occupied more than six hours to unload, and when the last essentials of a span arrived in the train, the erection usually began within twenty-four hours.

When the work of erection commenced after the floods of 1877, before which time the course of the river had been along the upper side of the bridge, this just abandoned channel passed under the bridge, with a depth of 17 feet near the north abutment, and was inclined to silt up at its ends; while the main stream, crossing with a depth of 50 or 60 feet, near the south abutment, had a strong tendency to encroach on the northern bank. Thus all but two spans at the north, and one span at the south end, were either in the water or on an isolated sand-bank, and this sand-bank was itself exposed to gradual erosion. Under these circumstances steps were taken to confine the deep stream to the second and third southern spans, with at most one surplus channel under the fourth span to carry off small freshets. To this end a dam of brushwood was thrown across the old channel at the north side of the third southern span, and in rear of this, at the north side of the fourth span, a dam of sand, faced with fascines, &c., closed the old channel. This allowed of the old channel being filled up along the line of the bridge with embankments of sand, on which the staging for the girders and the service tramways were laid.

Meanwhile the men were trained on the erection of the second northern span, which remained connected with the shore; but the end spans, which were blocked up in the stone and always accessible, were left untouched till all the girder work had been safely landed in India. Had one or two spans been lost or delayed, these end openings would have been filled up with staging, and traffic could have been maintained, even through the floods.

The stages had four lines of posts, the inner 18 feet apart being directly under the girders; and the outer 36 feet apart under the crane rails. In elevation the posts were so spaced as to come vertically under the camber blocks, at either side of each joint in the booms. This divided the whole into ten four-post trestles, about 9 feet square on either side, with nine spans of about 16 feet between them. Each trestle was removed whole, and only the span-beams and central cross-bracings were dismantled. About 10,000 cubic feet of timber were required for each complete stage. The long sleepers under the trestles were spiked to the sills, and had iron chairs fitted to them for sliding the trestles along the rails. Designed to be removable in ten days, these stages answered the purpose well; and in the later spans a stage took only seven days from slacking the wedges of one girder to beginning the booms of another. The four Wellington travelling cranes were 36 feet high and 36 feet span, which just allowed trollies of 5 feet 6 inches gauge passing between the leg of the crane and the girder. The cast-iron double-flanged bearing wheels of the crane had all to be replaced after giving much trouble.

The work of erection and riveting was only carried on by daylight, although two Gramme dynamo-electric machines, with Serrin regulators, were kept in hand. With such reckless workmen as

Punjabees, nothing but the most serious emergency would justify night-work, and it was never resorted to. The usual provision of water and sand for extinguishing fires was kept in the booms, and the sub-divisional officers personally saw all fires extinguished at night, and kept a check on the night watchmen.

The weight of a complete span was 419 tons, and 180 tons of rails and sleepers (the only material available) were erected as scaffolding for the riveters. To put up and service-bolt this weight of 600 tons occupied at first eighteen days, latterly only seven days, with one crane; with two cranes on a span the time was gradually reduced from twelve days to three days and a half.

Allowing for sick and disabled men, the riveting work required close on three hundred gangs, and these were with difficulty collected from all parts of India, as far as Bombay and Calcutta. But the men were mostly unequal to knocking down a 1-inch rivet; and even after the sturdier well-sinkers and erectors (mostly boatmen by profession) were taught to do the work with heavy hammers, the waste of rivets was about 50 per cent., instead of 20, as usual. The best gangs rarely put in one hundred good rivets in a day, and the average was not much more than thirty. The rate paid (Rs. 9 per hundred 1-inch rivets) for labour only was about double the price in England. Bad as were the hammermen, the holders up were worse; and a man too listless to hold up for two minutes would spend an hour, if unwatched, in caulking a slack rivet to pass it off as sound. In the end the foreman riveter, Mr. Macpherson, devised an ingenious telescopic dolly to be keyed up to the work by a large cotter, and this was most successful. Riveting was begun as soon as the lower booms were put down, and the complete riveting of a span occupied at first ten or twelve, and latterly only four or five, days longer than the erection of the ironwork. The last span over the water was erected and riveted, so far that the trusses were secure and self-supporting, in forty-five working hours, and the span was completed in eight working days. There were about thirty-five thousand rivets per span to be fixed in India, about half of which were 1-inch rivets, and the rest smaller.

More than thirty thousand service-bolts were made for fastening the work together. Freight and carriage in India came to Rs. 83½, or about £6 15*s.* per ton. Staging alone (after deducting the selling value of the materials, which is never much) added Rs. 20, or say 32*s.* 6*d.* per ton all round; and the remaining charges, from unloading from wagons to completion all but painting, cost Rs. 66½, say £5 7*s.*, including all the tools, service bolts, and an extra 30 per cent. of rivets made by hand in India.

The floor of the bridge is ultimately to be asphalted, but was meanwhile covered with ashes for the use of the Kandahar column. The gaps from girder to girder are covered with a platform of sleepers resting on the end cross-girders, but not fixed to them, on account of the girders expanding and contracting. In the middle of the gap this platform is spiked to a cross-girder, which being of wood, and resting only on masonry supports at the ends, is elastic under a load; in fact no jar is perceptible as the engine crosses the piers.

The masonry of the piers is finished with an open brickwork cornice of the same depth as the bearing saddles. The spaces between the cornice brackets admit air and light, and serve to drain off rain-water. End turrets, with spiral stairs and hand-rails on the top booms, are required to finish off the work and to prepare it for passenger traffic.

The colony of Adamwahan, with temporary residences for a large staff, two hospitals, a cemetery, a market, brick fields, store sheds, mortar-mills, workshops, &c., was in itself an important charge, and kept an assistant engineer and several subordinates in full work to look after the mere fabric of the buildings. The workshops were originally too small even for the requirements of the bridge, and were ultimately extended to meet the wants of 270 miles of railway, including the erection and repairs of locomotives and the construction of wagons and passenger carriages. There were likewise depôts of sleepers, rails, and fuel, 15 miles of sidings, of which the gauge was altered from 3 feet 3⅜ inches to 5 feet 6 inches, with a new native town of six thousand inhabitants, all enclosed within an embankment to exclude floods, which would otherwise destroy the whole place. Besides native workmen and petty contractors, the staff consisted of from six to eight engineers, twelve to fourteen foremen, about twenty European guards, drivers and fitters, and one hundred native subordinates, clerks, and time-keepers, &c. The housing of these cost a little more than £10,000. The staff will not appear large when the unhealthiness of the place is considered. In the worst season it was not uncommon for three men out of four to be laid up simultaneously with fever; and one year, when a flood had broken into the place, one thousand labourers are believed to have died of pneumonia.

This communication is accompanied by several drawings on a small scale, from which Plates 2 and 3 have been engraved.

[APPENDIX.

APPENDIX.

THE EMPRESS SUTLEJ BRIDGE. TABULAR STATEMENT of COST EXCLUSIVE of WORKS for RECTIFYING RIVER CHANNELS.

Sterling values calculated from rupees at 1*s.* 8*d.*

Description.	Unit.	Quantity.	Rate.			Cost per Pier.	Total.	
			£.	s.	d.	£.	£.	£.
Seventeen brickwork piers 42 feet long, 14 feet thick, 30 feet high each, on three wells 19 feet in diameter and 103½ feet deep—								
Sinking per well . .	Lineal feet	6,500	10	8	10	3,993	67,877	
„ net	Cubic yards	59,260	1	2	11			
Masonry	„	60,544	0	19	7½	3,495	59,390	
Hearting wells . .	„	13,178	0	5	1	197	3,345	
Rubble protection .	„	90,010	0	13	1	3,453	58,695	
Ashlar girder beds .	Cubic feet	9,773	0	8	9	252	4,285	
Woodwork in curbs .	„	16,177	0	4	1	192	3,271	
Iron in bond bars .	Tons	332	39	17	11	786	13,196	210,059
Total for piers . .		..	..			12,368		
„ „ each pier per foot high .	..	..	..			92 11 3		
Sixteen wrought-iron spans, 250 feet clear, for single line of railway, with buckled-plate floor—								
Cost F. O. B. in England	Tons	6,704	14	1	7	5,904	94,455	
Freight by sea and rail	„	6,704	6	19	2	2,913	46,601	
Erecting staging, &c.	„	6,704	7	17	6	3,297	52,757	193,813
Total for spans . .	Per ton	..	28	18	3	12,114		
Contingencies, including temporary bridges, and sidings, houses for staff, and losses by floods	..	..	..			..	..	17,594
Total for whole bridge	..	..	..			..	..	421,466
„ per lineal foot on 4,224 feet .	..	..	..			..	..	99 15 7

(*Paper No. 1767.*)

"The Paroy Reservoir."

By WILLIAM BELL DAWSON, M.A., Assoc. M. Inst. C.E.

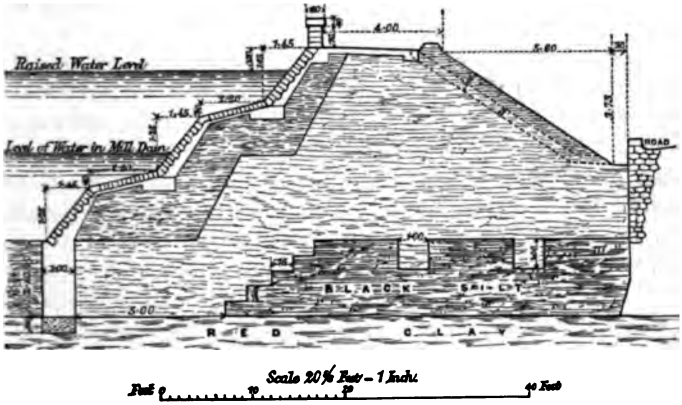
THE Marne-Rhine canal, which connects Paris with Strassburg, has two summits on its course; one where it passes from the head-waters of the Marne to the valley of the Moselle, the other in crossing the Vosges mountains before descending towards the valley of the Rhine. The latter is lower and wider than the other, and the summit-reach is rather more than 18 miles in length. This reach derives its supply from the head-waters of the Sarre, and from the Gondrexange pond, through which it passes, and of which the level has been raised to increase its capacity. From the summit-reach water is drawn off for the supply of the canal on both slopes, and also for a length of 12 miles on a branch from this point northward, through the coalfields of the valley of the Sarre. On the slope towards the Moselle the head-water has to do duty as far as the Réchicourt pond, of which the capacity has also been artificially increased, to afford storage for any surplus from the Gondrexange pond that may reach it along the canal, in addition to the rainfall of its own basin. Its capacity is 880,000,000 gallons, and it has to furnish the water necessary for the working of the canal as far as Dombasle, a length of about 24 miles. From this point an ample supply is derived from the Meurthe, a tributary of the Moselle, near to which the canal runs for a considerable distance.

The supply on this part of the canal was never more than barely sufficient, and a scheme had been elaborated some twelve years ago for supplementing it. The events of 1870–71 made a fundamental change in the data of the problem, as the position of the new frontier cut off from France the summit-reach of the Vosges, together with the Gondrexange and Réchicourt ponds, and upon these the supply of the slope towards the Moselle depended, of which the greater part still remained in France. By the International Convention of May 1873 however, Germany agreed to furnish sufficient water to maintain the depth of 5 feet 3 inches, which the canal had at that time. Subsequently, the French Government decided, by the Decree of the 8th of November, 1877, to increase the depth of water to 6 feet 6 inches; to carry this into effect an additional quantity of water had to be obtained. From an examination of the country, it was evident that no streams of importance could be made available as a source of supply, and that the best means of securing it would be by the construction of a reservoir which should depend entirely upon the rainfall on its own basin. This solution had the additional advantage of being independent of the political relations with a neighbouring country. It was not difficult to obtain the site for such a reservoir. At 4½ miles from the frontier, close to the canal, there was a mill-pond of considerable extent, situated in a valley consisting entirely of clay and marl, and whose sides sloped up uniformly to a considerable height. The east side of the valley, which is rather steeper than the other, consists of variegated marls lying almost horizontally. The lime in these marls has separated from the general mass, and occurs as thin layers of calcite, 2 or 3 inches in thickness, leaving between them beds of red, blue, and grey clay, of a consistency not affected by contact with standing water, and sufficiently compact and tenacious to form a good foundation for masonry structures. On the west side of the valley there is a heavy bed of rather soft red clay, which crumbles into flakes when exposed to the air. In the central part of the valley a deposit of black silt, 25 or 30 feet thick, occurs in the middle, thinning off towards the sides. This silt is soft and compressible at the surface, but firmer below. On exposure to the air it becomes as tough as brick clay, and shrinks into little cubes as it dries. These are homogeneous and fine-grained, and while moist are somewhat greasy.

The mill-pond that existed here was retained by an embankment of earth, which also served to carry across the valley the road from Dombasle to Sarrebourg. The level of the water was 4 feet 5 inches above that of the surface of the canal opposite. This level could be raised only 9 feet, otherwise the village of Bures, at the upper end of the valley, would be inundated. The volume contained between the level of the water in the reach opposite and this new level was found to be 350,000,000 gallons. The first point to be determined was, therefore, whether a reservoir with this available capacity would be sufficient to store the rainfall of its own basin, and meet the demand on the length of canal which it would be required to supply. No direct observations of a satisfactory character were available; but as the conditions of the Gondrexange pond had been studied for fourteen years, a comparison with it was thought admissible, as it is distant only 15 miles.

The rainfall and evaporation, respectively, were assumed to be equal at the two places, and the differences in the nature and character of the two basins were taken into account. The volume of water required for the supply of the canal being known, the problem presented no special difficulty. Tables were drawn up of the receipts and expenditure of the reservoir as they would have been during the fourteen years. From these it appeared that, during the driest season, there would have been one week (in the month of November, 1858), when the available quantity would have fallen to 3,000,000 gallons, after which the reservoir would have been replenished by the winter rains. This result was considered satisfactory, and as affording sufficient guarantee for the future.

Fig. 1.



Cross Section of the Embankment.

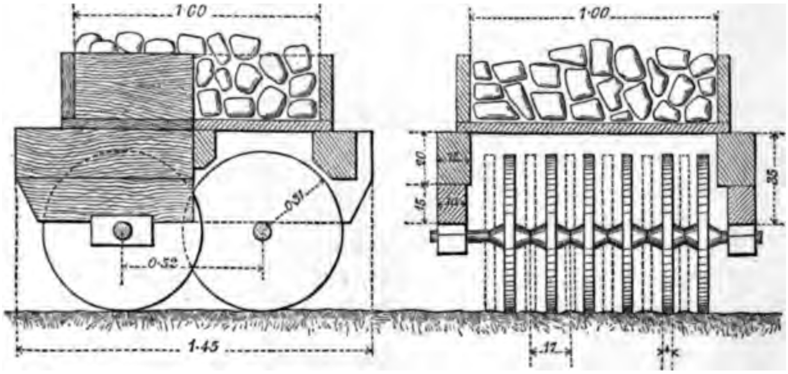
A suitable position for the retaining dam was indicated by the bank of the mill-pond. It was thought better to place the new dam in front of the old one rather than to modify the profile and height of the existing bank, to avoid the reconstruction of the roadway on its summit, and the interruption to the traffic which would necessarily result. The incorporation of a mass of earthwork of uncertain quality in the body of the new work was also obviated, and a much larger base was secured to the dam without additional expense. The profile of the dam (Fig. 1) is one which had been adopted before at the reservoirs of Montaubry and Mittersheim. The earthwork is stepped on the water side and faced with masonry, so designed that if any settlement does occur in the earthwork, it can only cause the angles between the successive steps to become slightly more obtuse, without producing cracks in the masonry. The earthwork on the water side is thus enabled to stand at an average slope of about 1½ to 1, which reduces the length of the slope to nearly one-half of what it would be at the ordinary inclination of 3 to 1. This again allows a layer of puddle of sufficient thickness to be placed on the water slope, as the reduction in its length brings down the volume of the puddle to an admissible quantity. It is protected by the masonry, and is in a position to perform its duty much more certainly and effectively than if placed in the centre of the dam as a puddle wall. It can also be carried down as far as necessary in a trench along the toe of the slope. The cost of the masonry facing is counterbalanced to some extent by a corresponding saving in the volume of the earthwork, and this becomes greater in proportion as the dam is of greater height. The crest of the dam rises 2 feet 3 inches above the water-level.

To take advantage of the good foundation on the east side of the valley, the waste weir and outlet works were combined into one structure. According to observation the maximum storm rainfall amounts to 40,000 gallons per minute for the basin. The length of the overflow was calculated so that this quantity of water entering the reservoir for a period of thirty-six hours would not raise the water more than 8 inches above the crest of the waste weir, supposing the outlet gates to remain closed. The water from the reservoir passes into an intermediate basin, from which it can be admitted to the canal or be turned into a waste-water channel. This basin was placed on the site of an old borrow-pit made during the construction of the canal.

The material for the body of the dam was selected from among the marls and clays at the sides of the valley. The puddle for the inner side of the work was obtained from a natural deposit of sandy clay situated at a distance of 1000 yards from the works. This was mixed with one-tenth of its volume of slaked lime before being used. It was originally intended to carry up the earthwork as far as possible during the first complete working season, to allow the reservoir to fill with water during the succeeding winter to complete the settlement and consolidation of the work, and to construct the masonry facing in the summer following. After the contract was let it was abandoned, on account of the difficulties met with in excavating the silt in the central part of the valley; and the work was carried on by day labour under the supervision of the engineer in charge. The delay occasioned in reorganizing the work made it impracticable to conform to this plan without an unwarrantable increase in the time occupied in its execution. To secure the same advantages, it was decided to keep the earthwork constantly wet by a small force-pump, and to pay special attention to its consolidation.

To prepare a seat for the bank it was necessary to remove a large quantity of the silt occupying the bottom of the valley. After the water of the mill-pond was let out, an excavation in the silt, 16 feet wide measured back from the toe of the water slope, was commenced at the centre of the valley. This was carried down till the silt was found sufficiently compact to resist a pressure of 2½ tons on the square foot (2·60 kilogrammes per square centimetre) without yielding appreciably. A depth of 13 feet satisfied this condition. From the lower side of this excavation the silt was stepped back toward the road. A small hand-pump was sufficient to keep it free from water. The earth, in filling in, was spread in layers 10 inches in thickness, and was carried up so as to leave a trench 5 feet in width between it and the upper side of the excavation. This trench was destined to receive the masonry wall along the toe of the water slope; but it was found necessary to fill it temporarily with sand, which was carefully punned and brought up to the natural surface of the ground to support the silt which would not stand alone. As the excavation extended from the centre toward the sides of the valley, sufficiently firm ground was found at a less depth; and it soon became possible to remove the silt entirely, and to seat the earthwork on the clay below.

FIG. 2.



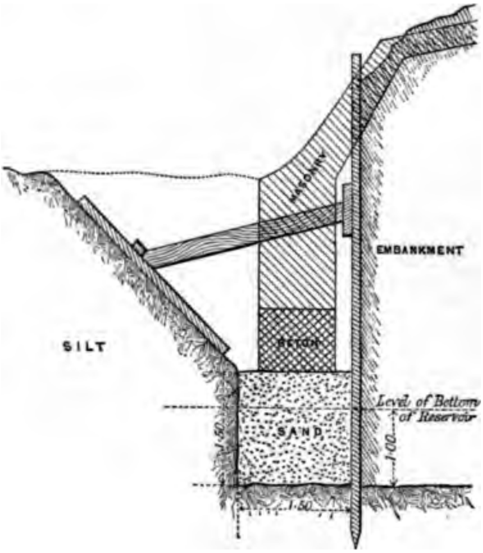
Half elevation. Half section. Transverse section.

COMPRESSION-ROLLER.

Scale $\frac{1}{30}$ of real size.

After the excavation had been filled in to the natural surface of the ground, the work presented less difficulty. The puddle on the water slope was carried up at the same time with the earthwork of the body of the dam. The successive layers were partly consolidated by the passage of the carts in which the material was brought. In addition, a compression-roller was used. It was of the design shown in Fig. 2, and weighed, when empty, 25 cwt. An additional load of 16 cwt. of stone could be placed in the box. It was drawn by four horses, and the pole was attached to an iron hoop running in guides at the four corners of the box, to avoid turning the roller before commencing the return trip. The final measurements showed that the earthwork had become so thoroughly packed as to occupy nearly the same volume as that of the borrow-pits from which it had been taken. This method of consolidation cost $\frac{1}{2}d.$ per cubic yard of earthwork. Near the masonry of the overflow and outlet works maidens of cast-iron, weighing 35 lbs., were used, and of hemispherical form below, to prevent fouling.

Fig. 3.



Foundation of the masonry facing in the central part of the valley, as actually built.
Scale $\frac{1}{100}$ of real size.

As the dam rose in height, the toe of the water-slope advanced slightly. The amount nowhere exceeded 6 inches, and when the full height was reached the movement ceased. During the latter part of the same season in which the earthwork was completed, the masonry facing was commenced. In building the wall along the toe of the water-slope, light sheet piling was driven on the side next the bank, and the temporary sand-filling was taken out to a depth of 8 feet. The silt on the other side was sloped back and the opening shored, as shown in Fig. 3. By the end of the season the masonry was brought up to about one-half the height of the dam, and during the following winter the reservoir was partially filled. In the spring the facing was carried up to the full height of the dam, and the whole of the works were completed by the autumn of 1878.

SUMMARY of COST.

	£.	£.
The Paroy Mill Pond, including the old dam, the mill, &c.	8,000	
Land up to the contour line at 1 foot above the normal water-level of the reservoir	5,400	
Indemnities	200	
Total purchases		13,600
Earthwork, and excavation in the foundations . .	3,320	
Masonry facing	2,400	
Overflow and outlet works	1,340	
Accessories	140	
Extras, estimated at schedule prices	600	
Total for construction		7,800
Grand total		21,400

(*Paper No. 1802.*)

"Dredging on the Lower Danube."

By Charles Henry Leopold Kühl, M. Inst. C.E.

The European Commission of the Danube has now charge of the lower river from the Roumanian town of Galatz, 92 nautical miles from Sulina to the sea, the powers of the Commission having been extended over the part of the river from Isaktcha to Galatz by the Treaty of Berlin in 1878.

The important works at the Sulina mouth of the river have been described by the Engineer-in-chief of the European Commission, Sir Charles A. Hartley, M. Inst. C.E.[1] No dredging has been required at the Sulina mouth, the scour caused by the piers having been sufficient to form and maintain a commodious channel, with a depth of 20½ feet across the old bar. The Sulina branch from the sea to the 18th mile has not required improvement, the channel being regular, and having a depth of not less than 17 feet at zero. A shoal, which extended from 18½ to 19½ miles, was removed by the construction of groynes in 1861–62. From the 20th mile to the St. George's chatal, or bifurcation, at the upper end of the Sulina branch, 44½ nautical miles from the sea, shoals are frequent; many have been removed, but new ones appear from time to time. An isolated shoal at the 54th mile, the Ismail chatal, having been dredged and permanently removed by training works executed in 1873, the part of the river between 44½ miles and Galatz has been cleared of its single obstruction. The only section of the lower Danube now requiring improvement is consequently the upper part of the Sulina branch, from 20 to 44½ miles. Before the existence of the European Commission, the minimum depth in the Sulina branch was 8 feet. Up to the present time an extra depth of 5 feet has been gained. Dredging and other works have been constantly required, the object being to secure a minimum depth of 15 feet at zero.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxi., p. 277, and vol. xxxvi., p. 37.

In dealing with the shoals in the lower Danube, it is, considering the vast quantities of sediment and sand carried in suspension by the river during floods, practically or financially impossible to effect permanent improvement by dredging alone. The average quantity of detritus transported by the Sulina branch is above 5,000,000 tons per annum. During ordinary land floods 50,000 tons in twenty-four hours are frequent, and the extraordinary quantity of 135,000 tons in twenty-four hours has been reached on several occasions, when the average quantity of sediment in suspension amounted to 980 grains per cubic foot. The latter occurrence takes place after very heavy rains in the Roumanian plains. These plains consist of rich loam, easily carried away by attrition, and readily transported by the swift current of the lower tributaries of the Danube on the left bank, the Pruth, Seroth, &c.

Shoals occur in reaches of the river which are of an abnormal width, by preference between counter curves in the river course, where in consequence the main current and the channel have to cross the river-bed from one concave bank to the other opposite and below; also in long straight reaches, where, instead of following one bank as in curves, the main current meanders over the whole area of the river section from one bank to the other. These can only be permanently dealt with by the construction of groynes, or training works, reducing the river to its normal width.

The shoals in the Sulina branch are subject to constant changes, increasing during floods, and being gradually worn down during low-water seasons. The range between the maximum flood level and extreme low water at the upper end of the Sulina branch is 12 feet. A shoaling of 3 feet has been known to take place within twenty-four hours, when no particular reason for its sudden formation could be assigned; in many cases, however, where ships have grounded, a small bank has formed below before the ship could be got off, which in its turn has disturbed the regularity of the current, forming a series of banks below, and causing a whole reach to shoal. In these cases, when the construction of groynes would take months to execute, dredging is at once resorted to, and gives immediate relief, re-establishing the former depth in the shortest possible time. Under ordinary circumstances dredging operations on the shoal offering the least depth at zero are proceeded with as soon as the spring land-flood begins to subside, which generally takes place in June. This equalises the depths on the different shoals, and assists in maintaining a deep and uniform channel during the period of low water in the autumn, which coincides with the greatest activity of navigation, the new crops of the Danubian Principalities being exported immediately after the harvest. The channel dredged across shoals is, as a rule, of a width of 150 feet, and 15 feet deep below zero. The time occupied in dredging the shoals is very variable, six months having been required in 1872, seven months in 1873, one month in 1875, three months in 1876, and one month in 1880.

The shoals consist chiefly of fine sand; but at Veniko, at the 37th mile, a shelf of hard clay, which the current had not been able to remove, was met with in dredging to 15 feet below zero, and the same occurred in the Argagnis reach, at the 41st and 42nd mile, and a permanent increase of depth was thus obtained. On the ordinary shoals the increase of depth by dredging is as a rule lost during the first flood after the operation.

The European Commission has at present two ordinary bucket steam-dredgers, the one of 16 HP. nominal, the other of 40 HP.; another 40-HP. dredger is being built. The dredgers are open-ended single-ladder machines, fitted with Messrs. Burt and Freeman's mud-pumps, as used on the Amsterdam ship canal, and now employed on the St. Petersburg ship canal. These pumps have been fully described in "Engineering;"[1] for dredging shoals consisting of fine sand, in some cases slightly mixed with vegetable deposit and alluvial silt, they answer admirably. The Sulina branch has a maximum width of 600 feet, so that either bank can in every case be easily reached by the floating tubes, and the height of the banks above ordinary low water hardly ever exceeds 8 feet, which is also very suitable. The excavated material is thus got rid of in the most efficient and economical manner.

The 40-HP. power steam-dredger has a length of 115 feet, a breadth of beam of 25 feet, and a depth of 10 feet 9 inches. It has a single side-lever low-pressure engine with tubular boiler, and can dredge 1,300 cubic yards per day of twelve working hours in favourable ground, to a maximum depth of 24 feet. The 16-HP. dredger has not been used lately. It requires nearly the same crew as the 40-HP. machine, is antiquated and not economical.

The Sulina branch in its upper part being very tortuous, there is ample room for improving it by cuts, for shortening and straightening the course by suppressing sharp bends, which, as steamers navigating the river increase in size and number, become more and more objectionable. The largest steamer which has passed through it up to the present, had a length of 300 feet, a net register of 1,384 tons, and 2,036 tons gross.

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[1] July 17th, 1868; and again November 8th, 1872.

The cut between the 23rd and 24th mile was finished in 1870. It shortens the river by 5,790 feet, and does away with three of the worst bends. The length of the cutting is 1,900 feet; its bottom width was 180 feet, and depth 16 feet below zero. This cutting was widened in 1874–75 to a bottom width of 260 feet. The width at the waterline at zero is 300 feet. The old part of the river cut-off has now silted up entirely in its upper end without artificial aid, and is overgrown by willow bushes several feet high.

A second cut is under execution at the St. George's chatal, with a view of giving an improved entrance to the upper end of the Sulina branch. This cut has a length of 3,100 feet; it will do away with two sharp bends, and shorten the river by 2,900 feet. The bottom width is 260 feet, and the width at zero is 300 feet. It will be dredged to a depth of 16 feet below zero, or deeper if the scour does not itself produce the normal section. Of the 869,000 cubic yards to be removed, 123,750 were dredged last year by the 40-HP. machine. The site of this cut consists of alluvial deposit, the same as the whole of the delta. The height of the ground varies from 4 feet above zero in the middle of the cutting to 11 feet above zero near the river banks. The upper stratum is very hard clay and loam interlaced with the strong and tenacious roots of reeds, for a depth of several feet; below, layers of clay, vegetable deposit of a peaty nature, and fine river sand occur in irregular layers. The clay, down to 12 feet below the waterline, is dredged into hopper barges, which are towed into the St. George's branch, and discharged behind the St. George's chatal spur, close to the left bank of the river, the average distance being 4,000 feet. The lower sandy layers will be removed by dredging in combination with the mud pump.

The prime cost of the plant employed has been as follows:—

	£
One steam-dredger 40 HP. nominal	14,700
„ screw steamer for towing of 15 HP.	800
Two bottom hopper barges (capacity 90 cubic yards).	3,200
„ side „ („ 30 „).	880
Total	19,580

The cost of dredging per cubic yard has averaged as under:—

		Pence per Cubic yard.	Pence per Cubic yard.	Pence per Cubic yard.
Dredger	Coal and stores	0·675	1·944	3·102
	Crew and wages	1·269		
Repairs of Dredger	Stores	0·341	1·158	
	Labour	0·817		
Transport:—				
Towage 4,000 feet	Coal and stores	0·362	0·586	1·050
	Crew	0·224		
Hopper barges	Stores	0·020	0·464	
	Crew	0·444		
	Total	4·152	4·152	

This is the actual cost for wages and stores, including repairs of plant, but excluding the cost of plant, depreciation and interest. In estimating for these latter items the quantity dredged and transported per annum by the above plant would have to be taken at 250,000 cubic yards, as no more than two hundred working days per annum can be counted upon on the lower Danube, the winter being long and rigorous.

When using the mud-pump in combination with the dredger, the engine has to exert greater power; additional men for looking after the tubes are also required. This does away with the transport, but slightly enhances the cost of dredging proper, which becomes 2·592*d.* per cubic yard for wages, coals, and stores, making a total cost of 3·750*d.* per cubic yard, including repairs. The cost of repairs of the wear and tear of the dredger, 1·158*d.* per cubic yard, is high. In pure clay, of a soapy nature, it would be less; it is due to the sand, which cuts up the links and buckets. The age of the dredger, which was built in 1866, must also be taken into account.

For comparison with other places, it must be remarked that the price of coals on the lower Danube is at present from 26*s.* to 30*s.* per ton. Stores are proportionately expensive, as compared with prices in England. Wages are high for skilled labour. Sailors earn 3*s.* per day; labourers, 2*s.* 6*d.*

(*Paper No. 1796.*)

"Logarithms of the Values of all Vulgar Fractions, with Numerator and Denominator not exceeding 100, arranged in Order of Magnitude."

By Sir George Biddell Airy, K.C.B., F.R.S., Hon. M. Inst. C.E.

Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.
$\frac{100}{99}$	·00436	5	$\frac{82}{81}$	·00532	8	$\frac{64}{63}$	·00684	11	$\frac{48}{47}$	·00914	10
$\frac{99}{98}$	·00441	5	$\frac{81}{80}$	·00540	6	$\frac{63}{62}$	·00695	11	$\frac{95}{93}$	·00924	10
$\frac{98}{97}$	·00446	4	$\frac{80}{79}$	·00546	8	$\frac{62}{61}$	·00706	12	$\frac{47}{46}$	·00934	10
$\frac{97}{96}$	·00450	5	$\frac{79}{78}$	·00554	6	$\frac{61}{60}$	·00718	12	$\frac{93}{91}$	·00944	11
$\frac{96}{95}$	·00455	4	$\frac{78}{77}$	·00560	8	$\frac{60}{59}$	·00730	12	$\frac{46}{45}$	·00955	10
$\frac{95}{94}$	·00459	6	$\frac{77}{76}$	·00568	7	$\frac{59}{58}$	·00742	14	$\frac{91}{89}$	·00965	11
$\frac{94}{93}$	·00465	4	$\frac{76}{75}$	·00575	8	$\frac{58}{57}$	·00756	12	$\frac{45}{44}$	·00976	11
$\frac{93}{92}$	·00469	6	$\frac{75}{74}$	·00583	8	$\frac{57}{56}$	·00768	15	$\frac{89}{87}$	·00987	11
$\frac{92}{91}$	·00475	5	$\frac{74}{73}$	·00591	8	$\frac{56}{55}$	·00783	14	$\frac{44}{43}$	·00998	12
$\frac{91}{90}$	·00480	5	$\frac{73}{72}$	·00599	8	$\frac{55}{54}$	·00797	14	$\frac{87}{85}$	·01010	12
$\frac{90}{89}$	·00485	6	$\frac{72}{71}$	·00607	9	$\frac{54}{53}$	·00811	17	$\frac{43}{42}$	·01022	12
$\frac{89}{88}$	·00491	5	$\frac{71}{70}$	·00616	9	$\frac{53}{52}$	·00828	15	$\frac{85}{83}$	·01034	13
$\frac{88}{87}$	·00496	6	$\frac{70}{69}$	·00625	9	$\frac{52}{51}$	·00843	17	$\frac{42}{41}$	·01047	12
$\frac{87}{86}$	·00502	6	$\frac{69}{68}$	·00634	10	$\frac{51}{50}$	·00860	17	$\frac{83}{81}$	·01059	13
$\frac{86}{85}$	·00508	6	$\frac{68}{67}$	·00644	9	$\frac{50}{49}$	·00877	10	$\frac{41}{40}$	·01072	14
$\frac{85}{84}$	·00514	6	$\frac{67}{66}$	·00653	10	$\frac{99}{97}$	·00887	9	$\frac{81}{79}$	·01086	14
$\frac{84}{83}$	·00520	7	$\frac{66}{65}$	·00663	10	$\frac{49}{48}$	·00896	9	$\frac{40}{39}$	·01100	14
$\frac{83}{82}$	·00527	5	$\frac{65}{64}$	·00673	11	$\frac{97}{95}$	·00905	9	$\frac{79}{77}$	·01114	14

Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.
39/38	·01128	15	29/28	·01524	18	91/87	·01952	8	75/71	·02380	11
77/75	·01143	15	86/83	·01542	9	68/65	·01960	14	56/53	·02391	9
38/37	·01158	16	57/55	·01551	10	45/43	·01974	15	93/88	·02400	13
75/73	·01174	16	85/82	·01561	19	67/64	·01989	8	37/35	·02413	14
37/36	·01190	16	28/27	·01580	19	89/85	·01997	23	92/87	·02427	9
73/71	·01206	17	83/80	·01599	9	22/21	·02020	24	55/52	·02436	11
36/35	·01223	18	55/53	·01608	10	87/83	·02044	8	73/69	·02447	7
71/69	·01241	18	82/79	·01618	21	65/62	·02052	17	91/86	·02454	28
35/34	·01259	19	27/26	·01639	21	43/41	·02069	16	18/17	·02482	29
69/67	·01278	19	80/77	·01660	11	64/61	·02085	8	89/84	·02511	8
34/33	·01297	19	53/51	·01671	11	85/81	·02093	26	71/67	·02519	12
67/65	·01316	7	79/76	·01682	21	21/20	·02119	26	53/50	·02531	9
100/97	·01323	13	26/25	·01703	23	83/79	·02145	9	88/83	·02540	16
33/32	·01336	15	77/74	·01726	11	62/59	·02154	18	35/33	·02556	15
98/95	·01351	6	51/49	·01737	12	41/39	·02172	18	87/82	·02571	9
65/63	·01357	7	76/73	·01749	24	61/58	·02190	10	52/49	·02580	14
97/94	·01364	15	25/24	·01773	19	81/77	·02200	28	69/65	·02594	7
32/31	·01379	14	99/95	·01792	5	20/19	·02228	23	86/81	·02601	32
95/92	·01393	8	74/71	·01797	13	99/94	·02251	6	17/16	·02633	32
63/61	·01401	8	49/47	·01810	12	79/75	·02257	9	84/79	·02665	8
94/91	·01409	15	73/70	01822	7	59/56	·02266	9	67/63	·02673	14
31/30	·01424	16	97/93	·01829	19	98/93	·02275	11	50/47	·02687	12
92/89	·01440	8	24/23	·01848	20	39/37	·02286	12	83/78	·02699	16
61/59	·01448	8	95/91	·01868	7	97/92	·02298	9	33/31	·02715	17
91/88	·01456	16	71/68	·01875	14	58/55	·02307	10	82/77	·02732	12
30/29	·01472	17	47/45	·01889	14	77/73	·02317	6	49/46	·02744	14
89/86	·01489	9	70/67	·01903	6	96/91	·02323	25	65/61	·02758	10
59/57	·01498	8	93/89	·01909	22	19/18	·02348	26	81/76	·02768	5
88/85	·01506	18	23/22	·01931	21	94/89	·02374	6	97/91	·02773	30

Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.
$\frac{16}{15}$	·02803	30	$\frac{69}{64}$	·03267	12	$\frac{86}{79}$	·03687	12	$\frac{11}{10}$	·04139	45
$\frac{95}{89}$	·02833	7	$\frac{55}{51}$	·03279	9	$\frac{49}{45}$	·03699	15	$\frac{98}{89}$	·04184	5
$\frac{79}{74}$	·02840	9	$\frac{96}{89}$	·03288	12	$\frac{61}{56}$	·03714	11	$\frac{87}{79}$	·04189	7
$\frac{63}{59}$	·02849	16	$\frac{41}{38}$	·03300	17	$\frac{73}{67}$	·03725	8	$\frac{76}{69}$	·04196	10
$\frac{47}{44}$	·02865	12	$\frac{68}{63}$	·03317	7	$\frac{85}{78}$	·03733	5	$\frac{65}{59}$	·04206	13
$\frac{78}{73}$	·02877	19	$\frac{95}{88}$	·03324	18	$\frac{97}{89}$	·03738	41	$\frac{54}{49}$	·04219	10
$\frac{31}{29}$	·02896	20	$\frac{27}{25}$	·03342	19	$\frac{12}{11}$	·03779	41	$\frac{97}{88}$	·04229	12
$\frac{77}{72}$	·02916	13	$\frac{94}{87}$	·03361	7	$\frac{95}{87}$	·03820	7	$\frac{43}{39}$	·04241	14
$\frac{46}{43}$	·02929	17	$\frac{67}{62}$	·03368	18	$\frac{83}{76}$	·03827	8	$\frac{75}{68}$	·04255	20
$\frac{61}{57}$	·02946	9	$\frac{40}{37}$	·03386	12	$\frac{71}{65}$	·03835	11	$\frac{32}{29}$	·04275	18
$\frac{76}{71}$	·02955	7	$\frac{93}{86}$	·03398	10	$\frac{59}{54}$	·03846	17	$\frac{85}{77}$	·04293	11
$\frac{91}{85}$	·02962	34	$\frac{53}{49}$	·03408	13	$\frac{47}{43}$	·03863	12	$\frac{53}{48}$	·04304	12
$\frac{15}{14}$	·02996	35	$\frac{66}{61}$	·03421	10	$\frac{82}{75}$	·03875	17	$\frac{74}{67}$	·04316	6
$\frac{89}{83}$	·03031	7	$\frac{79}{73}$	·03431	6	$\frac{35}{32}$	·03892	14	$\frac{95}{86}$	·04322	25
$\frac{74}{69}$	·03038	11	$\frac{92}{85}$	·03437	39	$\frac{93}{85}$	·03906	9	$\frac{21}{19}$	·04347	24
$\frac{59}{55}$	·03049	18	$\frac{13}{12}$	·03476	40	$\frac{58}{53}$	·03915	11	$\frac{94}{85}$	·04371	7
$\frac{44}{41}$	·03067	14	$\frac{90}{83}$	·03516	7	$\frac{81}{74}$	·03926	25	$\frac{73}{66}$	·04378	12
$\frac{73}{68}$	·03081	23	$\frac{77}{71}$	·03523	10	$\frac{23}{21}$	·03951	26	$\frac{52}{47}$	·04390	12
$\frac{29}{27}$	·03104	22	$\frac{64}{59}$	·03533	14	$\frac{80}{73}$	·03977	10	$\frac{83}{75}$	·04402	18
$\frac{72}{67}$	·03126	15	$\frac{51}{47}$	·03547	11	$\frac{57}{52}$	·03987	9	$\frac{31}{28}$	·04420	22
$\frac{43}{40}$	·03141	11	$\frac{89}{82}$	·03558	13	$\frac{91}{83}$	·03996	16	$\frac{72}{65}$	·04442	16
$\frac{100}{93}$	·03152	7	$\frac{38}{35}$	·03571	20	$\frac{34}{31}$	·04012	18	$\frac{41}{37}$	·04458	13
$\frac{57}{53}$	·03159	13	$\frac{63}{58}$	·03591	8	$\frac{79}{72}$	·04030	13	$\frac{92}{83}$	·04471	10
$\frac{71}{66}$	·03172	7	$\frac{88}{81}$	·03599	22	$\frac{45}{41}$	·04043	19	$\frac{51}{46}$	·04481	16
$\frac{85}{79}$	·03179	6	$\frac{25}{23}$	·03621	22	$\frac{56}{51}$	·04062	12	$\frac{61}{55}$	·04497	11
$\frac{99}{92}$	·03185	34	$\frac{87}{80}$	·03643	9	$\frac{67}{61}$	·04074	9	$\frac{71}{64}$	·04508	9
$\frac{14}{13}$	·03219	34	$\frac{62}{57}$	·03652	8	$\frac{78}{71}$	·04083	7	$\frac{81}{73}$	·04517	6
$\frac{97}{90}$	·03253	6	$\frac{99}{91}$	·03660	12	$\frac{89}{81}$	·04090	6	$\frac{91}{82}$	·04523	53
$\frac{83}{77}$	·03259	8	$\frac{37}{34}$	·03672	15	$\frac{100}{91}$	·04096	43	$\frac{10}{9}$	·04576	49

Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.
$\frac{99}{89}$	·04625	5	$\frac{82}{73}$	·05049	6	$\frac{67}{59}$	·05522	8	$\frac{85}{74}$	06019	10
$\frac{89}{80}$	·04630	7	$\frac{91}{81}$	·05055	6	$\frac{92}{81}$	·05530	22	$\frac{54}{47}$	·06029	13
$\frac{79}{71}$	·04637	9	$\frac{100}{89}$	·05061	54	$\frac{25}{22}$	·05552	24	$\frac{77}{67}$	·06042	6
$\frac{69}{62}$	·04646	11	$\frac{9}{8}$	·05115	56	$\frac{83}{73}$	·05576	10	$\frac{100}{87}$	·06048	22
$\frac{59}{53}$	·04657	18	$\frac{98}{87}$	·05171	5	$\frac{58}{51}$	·05586	9	$\frac{23}{20}$	·06070	26
$\frac{49}{44}$	·04675	10	$\frac{89}{79}$	·05176	7	$\frac{91}{80}$	·05595	16	$\frac{84}{73}$	·06096	9
$\frac{88}{79}$	·04685	14	$\frac{80}{71}$	·05183	9	$\frac{33}{29}$	·05611	21	$\frac{61}{53}$	·06105	9
$\frac{39}{35}$	·04699	19	$\frac{71}{63}$	·05192	11	$\frac{74}{65}$	·05632	16	$\frac{99}{86}$	·06114	13
$\frac{68}{61}$	·04718	7	$\frac{62}{55}$	·05203	15	$\frac{41}{36}$	·05648	13	$\frac{38}{33}$	·06127	14
$\frac{97}{87}$	·04725	18	$\frac{53}{47}$	·05218	9	$\frac{90}{79}$	·05661	12	$\frac{91}{79}$	·06141	11
$\frac{29}{26}$	·04743	21	$\frac{97}{86}$	·05227	12	$\frac{49}{43}$	·05673	17	$\frac{53}{46}$	·06152	14
$\frac{77}{69}$	·04764	13	$\frac{44}{39}$	·05239	14	$\frac{57}{50}$	·05690	14	$\frac{68}{59}$	·06166	9
$\frac{48}{43}$	·04777	15	$\frac{79}{70}$	·05253	18	$\frac{65}{57}$	·05704	10	$\frac{83}{72}$	·06175	6
$\frac{67}{60}$	·04792	9	$\frac{35}{31}$	·05271	14	$\frac{73}{64}$	·05714	9	$\frac{98}{85}$	·06181	34
$\frac{86}{77}$	·04801	29	$\frac{96}{85}$	·05285	9	$\frac{81}{71}$	·05723	7	$\frac{15}{13}$	·06215	34
$\frac{19}{17}$	·04830	31	$\frac{61}{54}$	·05294	9	$\frac{89}{78}$	·05730	5	$\frac{97}{84}$	·06249	6
$\frac{85}{76}$	·04861	8	$\frac{87}{77}$	·05303	21	$\frac{97}{85}$	·05735	64	$\frac{82}{71}$	·06255	9
$\frac{66}{59}$	·04869	16	$\frac{26}{23}$	·05324	20	$\frac{8}{7}$	·05799	65	$\frac{67}{58}$	·06264	15
$\frac{47}{42}$	·04885	14	$\frac{95}{84}$	·05344	8	$\frac{95}{83}$	·05864	7	$\frac{52}{45}$	·06279	11
$\frac{75}{67}$	·04899	23	$\frac{69}{61}$	·05352	17	$\frac{87}{76}$	·05871	7	$\frac{89}{77}$	·06290	15
$\frac{28}{25}$	·04922	18	$\frac{43}{38}$	·05369	18	$\frac{79}{69}$	·05878	9	$\frac{37}{32}$	·06305	14
$\frac{93}{83}$	·04940	8	$\frac{60}{53}$	·05387	11	$\frac{71}{62}$	·05887	11	$\frac{96}{83}$	·06319	9
$\frac{65}{58}$	·04948	21	$\frac{77}{68}$	·05398	7	$\frac{63}{55}$	·05898	14	$\frac{59}{51}$	·06328	11
$\frac{37}{33}$	·04969	16	$\frac{94}{83}$	·05405	31	$\frac{55}{48}$	·05912	20	$\frac{81}{70}$	·06339	28
$\frac{83}{74}$	·04985	13	$\frac{17}{15}$	·05436	31	$\frac{47}{41}$	·05932	12	$\frac{22}{19}$	·06367	24
$\frac{46}{41}$	·04998	18	$\frac{93}{82}$	·05467	7	$\frac{86}{75}$	·05944	14	$\frac{95}{82}$	·06391	7
$\frac{55}{49}$	·05016	15	$\frac{76}{67}$	·05474	11	$\frac{39}{34}$	·05958	19	$\frac{73}{63}$	·06398	14
$\frac{64}{57}$	·05031	10	$\frac{59}{52}$	·05485	20	$\frac{70}{61}$	·05977	23	$\frac{51}{44}$	·06412	12
$\frac{73}{65}$	·05041	8	$\frac{42}{37}$	·05505	17	$\frac{31}{27}$	·06000	19	$\frac{80}{69}$	·06424	22

Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.
29/25	·06446	18	61/52	·06933	9	70/59	·07425	8	95/79	·08009	7
94/81	·06464	8	88/75	·06942	21	89/75	·07433	30	89/74	·08016	7
65/56	·06472	22	27/23	·06963	26	19/16	·07463	33	83/69	·08023	8
36/31	·06494	18	74/63	·06989	15	82/69	·07496	10	77/64	·08031	10
79/68	·06512	15	47/40	·07004	16	63/53	·07506	19	71/59	·08041	11
43/37	·06527	12	67/57	·07020	9	44/37	·07525	17	65/54	·08052	13
93/80	·06539	11	87/74	·07029	29	69/58	·07542	8	59/49	·08065	18
50/43	·06550	17	20/17	·07058	27	94/79	·07550	22	53/44	·08083	9
57/49	·06567	15	93/79	·07085	8	25/21	·07572	26	100/83	·08092	12
64/55	·06582	11	73/62	·07093	14	81/68	·07598	11	47/39	·08104	12
71/61	·06593	9	53/45	·07107	11	56/47	·07609	11	88/73	·08116	14
78/67	·06602	8	86/73	·07118	17	87/73	·07620	19	41/34	·08130	17
85/73	·06610	6	33/28	·07135	21	31/26	·07639	17	76/63	·08147	20
92/79	·06616	6	79/67	·07156	14	99/83	·07656	8	35/29	·08167	16
99/85	·06622	73	46/39	·07170	18	68/57	·07664	20	99/82	·08183	7
7/6	·06695	74	59/50	·07188	12	37/31	·07684	18	64/53	·08190	9
97/83	·06769	6	72/61	·07200	9	80/67	·07702	15	93/77	·08199	20
90/77	·06775	7	85/72	·07209	6	43/36	·07717	13	29/24	·08219	23
83/71	·06782	8	98/83	·07215	40	92/77	·07730	12	81/67	·08242	11
76/65	·06790	10	13/11	·07255	41	49/41	·07742	18	52/43	·08253	14
69/59	·06800	11	97/82	·07296	6	55/46	·07760	16	75/62	·08267	7
62/53	·06811	15	84/71	·07302	9	61/51	·07776	12	98/81	·08274	24
55/47	·06826	20	71/60	·07311	12	67/56	·07788	11	23/19	·08298	26
48/41	·06846	12	58/49	·07323	20	73/61	·07799	10	86/71	·08324	10
89/76	·06858	13	45/38	·07343	15	79/66	·07809	7	63/52	·08334	21
41/35	·06871	17	77/65	·07358	21	85/71	·07816	7	40/33	·08355	13
75/64	·06888	20	32/27	·07379	19	91/76	·07823	5	97/80	·08368	9
34/29	·06908	15	83/70	·07398	12	97/81	·07828	90	57/47	·08377	13
95/81	·06923	10	51/43	·07410	15	6/5	·07918	91	74/61	·08390	8

Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.
$\frac{91}{75}$	·08398	34	$\frac{70}{57}$	·08923	17	$\frac{77}{62}$	·09410	17	$\frac{83}{66}$	·09954	16
$\frac{17}{14}$	·08432	32	$\frac{43}{35}$	·08940	21	$\frac{41}{33}$	·09427	15	$\frac{39}{31}$	·09970	19
$\frac{96}{79}$	·08464	8	$\frac{59}{48}$	·08961	12	$\frac{87}{70}$	·09442	14	$\frac{73}{58}$	·09989	23
$\frac{79}{65}$	·08472	10	$\frac{75}{61}$	·08973	8	$\frac{46}{37}$	·09456	12	$\frac{34}{27}$	·10012	16
$\frac{62}{51}$	·08482	19	$\frac{91}{74}$	·08981	37	$\frac{97}{78}$	·09468	11	$\frac{97}{77}$	·10028	9
$\frac{45}{37}$	·08501	16	$\frac{16}{13}$	·09018	39	$\frac{51}{41}$	·09479	19	$\frac{63}{50}$	·10037	10
$\frac{73}{60}$	·08517	26	$\frac{85}{69}$	·09057	9	$\frac{56}{45}$	·09498	15	$\frac{92}{73}$	·10047	20
$\frac{28}{23}$	·08543	20	$\frac{69}{56}$	·09066	15	$\frac{61}{49}$	·09513	13	$\frac{29}{23}$	·10067	23
$\frac{95}{78}$	·08563	8	$\frac{53}{43}$	·09081	11	$\frac{66}{53}$	·09526	13	$\frac{82}{65}$	·10090	13
$\frac{67}{55}$	·08571	20	$\frac{90}{73}$	·09092	16	$\frac{71}{57}$	·09539	9	$\frac{53}{42}$	·10103	13
$\frac{39}{32}$	·08591	16	$\frac{37}{30}$	·09108	15	$\frac{76}{61}$	·09548	10	$\frac{77}{61}$	·10116	30
$\frac{89}{73}$	·08607	12	$\frac{95}{77}$	·09123	10	$\frac{81}{65}$	·09558	7	$\frac{24}{19}$	·10146	25
$\frac{50}{41}$	·08619	17	$\frac{58}{47}$	·09133	12	$\frac{86}{69}$	·09565	7	$\frac{91}{72}$	·10171	8
$\frac{61}{50}$	·08636	12	$\frac{79}{64}$	·09145	6	$\frac{91}{73}$	·09572	6	$\frac{67}{53}$	·10179	20
$\frac{72}{59}$	·08648	9	$\frac{100}{81}$	·09151	26	$\frac{96}{77}$	·09578	113	$\frac{43}{34}$	·10199	20
$\frac{83}{68}$	·08657	7	$\frac{21}{17}$	·09177	29	$\frac{5}{4}$	·09691	110	$\frac{62}{49}$	·10219	12
$\frac{94}{77}$	·08664	51	$\frac{89}{72}$	·09206	9	$\frac{99}{79}$	·09801	6	$\frac{81}{64}$	·10231	6
$\frac{11}{9}$	·08715	52	$\frac{68}{55}$	·09215	17	$\frac{94}{75}$	·09807	6	$\frac{100}{79}$	·10237	29
$\frac{93}{76}$	·08767	7	$\frac{47}{38}$	·09232	15	$\frac{89}{71}$	·09813	8	$\frac{19}{15}$	·10266	32
$\frac{82}{67}$	·08774	9	$\frac{73}{59}$	·09247	8	$\frac{84}{67}$	·09821	8	$\frac{90}{71}$	·10298	9
$\frac{71}{58}$	·08783	12	$\frac{99}{80}$	·09255	20	$\frac{79}{63}$	·09829	9	$\frac{71}{56}$	·10307	15
$\frac{60}{49}$	·08795	19	$\frac{26}{21}$	·09275	26	$\frac{74}{59}$	·09838	11	$\frac{52}{41}$	·10322	13
$\frac{49}{40}$	·08814	12	$\frac{83}{67}$	·09301	10	$\frac{69}{55}$	·09849	12	$\frac{85}{67}$	·10335	19
$\frac{87}{71}$	·08826	16	$\frac{57}{46}$	·09311	11	$\frac{64}{51}$	·09861	14	$\frac{33}{26}$	·10354	21
$\frac{38}{31}$	·08842	21	$\frac{88}{71}$	·09322	20	$\frac{59}{47}$	·09875	17	$\frac{80}{63}$	·10375	15
$\frac{65}{53}$	·08863	10	$\frac{31}{25}$	·09342	18	$\frac{54}{43}$	·09892	22	$\frac{47}{37}$	·10390	19
$\frac{92}{75}$	·08873	21	$\frac{98}{79}$	·09360	8	$\frac{49}{39}$	·09914	11	$\frac{61}{48}$	·10409	12
$\frac{27}{22}$	·08894	20	$\frac{67}{54}$	·09368	22	$\frac{93}{74}$	·09925	13	$\frac{75}{59}$	·10421	8
$\frac{97}{79}$	·08914	9	$\frac{36}{29}$	·09390	20	$\frac{44}{35}$	·09938	16	$\frac{89}{70}$	·10429	45

Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.
$\frac{14}{11}$	·10474	42	$\frac{58}{45}$	·11022	20	$\frac{30}{23}$	·11539	25	$\frac{33}{25}$	·12057	25
$\frac{93}{73}$	·10516	8	$\frac{49}{38}$	·11042	12	$\frac{77}{59}$	·11564	16	$\frac{70}{53}$	·12082	22
$\frac{79}{62}$	·10524	10	$\frac{89}{69}$	·11054	16	$\frac{47}{36}$	·11580	18	$\frac{37}{28}$	·12104	20
$\frac{65}{51}$	·10534	17	$\frac{40}{31}$	·11070	20	$\frac{64}{49}$	·11598	12	$\frac{78}{59}$	·12124	18
$\frac{51}{40}$	·10551	12	$\frac{71}{55}$	·11090	25	$\frac{81}{62}$	·11610	7	$\frac{41}{31}$	·12142	17
$\frac{88}{69}$	·10563	17	$\frac{31}{24}$	·11115	22	$\frac{98}{75}$	·11617	34	$\frac{86}{65}$	·12159	14
$\frac{37}{29}$	·10580	16	$\frac{84}{65}$	·11137	13	$\frac{17}{13}$	·11651	37	$\frac{45}{34}$	·12173	14
$\frac{97}{76}$	·10596	9	$\frac{53}{41}$	·11150	13	$\frac{89}{68}$	·11688	9	$\frac{94}{71}$	·12187	13
$\frac{60}{47}$	·10605	12	$\frac{75}{58}$	·11163	8	$\frac{72}{55}$	·11697	14	$\frac{49}{37}$	·12200	22
$\frac{83}{65}$	·10617	29	$\frac{97}{75}$	·11171	26	$\frac{55}{42}$	·11711	11	$\frac{53}{40}$	·12222	18
$\frac{23}{18}$	·10646	30	$\frac{22}{17}$	·11197	33	$\frac{93}{71}$	·11722	16	$\frac{57}{43}$	·12240	17
$\frac{78}{61}$	·10676	13	$\frac{79}{61}$	·11230	12	$\frac{38}{29}$	·11738	16	$\frac{61}{46}$	·12257	14
$\frac{55}{43}$	·10689	12	$\frac{57}{44}$	·11242	11	$\frac{97}{74}$	·11754	10	$\frac{65}{49}$	·12271	14
$\frac{87}{68}$	·10701	20	$\frac{92}{71}$	·11253	18	$\frac{59}{45}$	·11764	12	$\frac{69}{52}$	·12285	11
$\frac{32}{25}$	·10721	24	$\frac{35}{27}$	·11271	19	$\frac{80}{61}$	·11776	34	$\frac{73}{55}$	·12296	10
$\frac{73}{57}$	·10745	18	$\frac{83}{64}$	·11290	14	$\frac{21}{16}$	·11810	31	$\frac{77}{58}$	·12306	10
$\frac{41}{32}$	·10763	15	$\frac{48}{37}$	·11304	19	$\frac{88}{67}$	·11841	9	$\frac{81}{61}$	·12316	8
$\frac{91}{71}$	·10778	13	$\frac{61}{47}$	·11323	13	$\frac{67}{51}$	·11850	19	$\frac{85}{64}$	·12324	8
$\frac{50}{39}$	·10791	18	$\frac{74}{57}$	·11336	9	$\frac{46}{35}$	·11869	18	$\frac{89}{67}$	·12332	6
$\frac{59}{46}$	·10809	14	$\frac{87}{67}$	·11345	6	$\frac{71}{54}$	·11887	8	$\frac{93}{70}$	·12338	7
$\frac{68}{53}$	·10823	11	$\frac{100}{77}$	·11351	43	$\frac{96}{73}$	·11895	24	$\frac{97}{73}$	·12345	149
$\frac{77}{60}$	·10834	9	$\frac{13}{10}$	·11394	46	$\frac{25}{19}$	·11919	29	$\frac{4}{3}$	·12494	147
$\frac{86}{67}$	·10843	6	$\frac{95}{73}$	·11440	7	$\frac{79}{60}$	·11948	13	$\frac{99}{74}$	·12641	5
$\frac{95}{74}$	·10849	65	$\frac{82}{63}$	·11447	10	$\frac{54}{41}$	·11961	13	$\frac{95}{71}$	·12646	7
$\frac{9}{7}$	·10914	67	$\frac{69}{53}$	·11457	15	$\frac{83}{63}$	·11974	24	$\frac{91}{68}$	·12653	8
$\frac{94}{73}$	·10981	7	$\frac{56}{43}$	·11472	11	$\frac{29}{22}$	·11998	21	$\frac{87}{65}$	·12661	8
$\frac{85}{66}$	·10988	8	$\frac{99}{76}$	·11483	13	$\frac{91}{69}$	·12019	10	$\frac{83}{62}$	·12669	9
$\frac{76}{59}$	·10996	11	$\frac{43}{33}$	·11496	17	$\frac{62}{47}$	·12029	10	$\frac{79}{59}$	·12678	9
$\frac{67}{52}$	·11007	15	$\frac{73}{56}$	·11513	26	$\frac{95}{72}$	·12039	18	$\frac{75}{56}$	·12687	11

Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.
$\frac{71}{53}$	·12698	12	$\frac{61}{45}$	·13212	12	$\frac{59}{43}$	·13738	15	$\frac{89}{64}$	·14321	21
$\frac{67}{50}$	·12710	14	$\frac{80}{59}$	·13224	8	$\frac{70}{51}$	·13753	11	$\frac{32}{23}$	·14342	27
$\frac{63}{47}$	·12724	16	$\frac{99}{73}$	·13232	30	$\frac{81}{59}$	·13764	8	$\frac{71}{51}$	·14369	21
$\frac{59}{44}$	·12740	18	$\frac{19}{14}$	·13262	35	$\frac{92}{67}$	·13772	58	$\frac{39}{28}$	·14390	19
$\frac{55}{41}$	·12758	21	$\frac{91}{67}$	·13297	8	$\frac{11}{8}$	·13830	57	$\frac{85}{61}$	·14409	16
$\frac{51}{38}$	·12779	12	$\frac{72}{53}$	·13305	17	$\frac{95}{69}$	·13887	8	$\frac{46}{33}$	·14425	13
$\frac{98}{73}$	·12791	12	$\frac{53}{39}$	·13322	12	$\frac{84}{61}$	·13895	9	$\frac{99}{71}$	·14438	12
$\frac{47}{35}$	·12803	14	$\frac{87}{64}$	·13334	20	$\frac{73}{53}$	·13904	14	$\frac{53}{38}$	·14450	18
$\frac{90}{67}$	·12817	15	$\frac{34}{25}$	·13354	21	$\frac{62}{45}$	·13918	19	$\frac{60}{43}$	·14468	15
$\frac{43}{32}$	·12832	16	$\frac{83}{61}$	·13375	15	$\frac{51}{37}$	·13937	13	$\frac{67}{48}$	·14483	12
$\frac{82}{61}$	·12848	18	$\frac{49}{36}$	·13390	18	$\frac{91}{66}$	·13950	16	$\frac{74}{53}$	·14495	11
$\frac{39}{29}$	·12866	21	$\frac{64}{47}$	·13408	12	$\frac{40}{29}$	·13966	22	$\frac{81}{58}$	·14506	8
$\frac{74}{55}$	·12887	23	$\frac{79}{58}$	·13420	8	$\frac{69}{50}$	·13988	9	$\frac{88}{63}$	·14514	7
$\frac{35}{26}$	·12910	24	$\frac{94}{69}$	·13428	42	$\frac{98}{71}$	·13997	21	$\frac{95}{68}$	·14521	92
$\frac{66}{49}$	·12934	10	$\frac{15}{11}$	·13470	46	$\frac{29}{21}$	·14018	27	$\frac{7}{5}$	·14613	93
$\frac{97}{72}$	·12944	19	$\frac{86}{63}$	·13516	10	$\frac{76}{55}$	·14045	17	$\frac{94}{67}$	·14706	7
$\frac{31}{23}$	·12963	22	$\frac{71}{52}$	·13526	15	$\frac{47}{34}$	·14062	19	$\frac{87}{62}$	·14713	9
$\frac{89}{66}$	·12985	11	$\frac{56}{41}$	·13541	10	$\frac{65}{47}$	·14081	12	$\frac{80}{57}$	·14722	10
$\frac{58}{43}$	·12996	12	$\frac{97}{71}$	·13551	15	$\frac{83}{60}$	·14093	40	$\frac{73}{52}$	·14732	12
$\frac{85}{63}$	·13008	25	$\frac{41}{30}$	·13566	21	$\frac{18}{13}$	·14133	34	$\frac{66}{47}$	·14744	16
$\frac{27}{20}$	·13033	29	$\frac{67}{49}$	·13587	10	$\frac{97}{70}$	14167	9	$\frac{59}{42}$	·14760	20
$\frac{77}{57}$	·13062	15	$\frac{93}{68}$	·13597	25	$\frac{79}{57}$	·14176	12	$\frac{52}{37}$	·14780	12
$\frac{50}{37}$	·13077	16	$\frac{26}{19}$	·13622	26	$\frac{61}{44}$	·14188	23	$\frac{97}{69}$	·14792	14
$\frac{73}{54}$	·13093	8	$\frac{89}{65}$	·13648	10	$\frac{43}{31}$	·14211	20	$\frac{45}{32}$	·14806	17
$\frac{96}{71}$	·13101	27	$\frac{63}{46}$	·13658	10	$\frac{68}{49}$	·14231	10	$\frac{83}{59}$	·14823	19
$\frac{23}{17}$	·13128	29	$\frac{100}{73}$	·13668	16	$\frac{93}{67}$	·14241	26	$\frac{38}{27}$	·14842	23
$\frac{88}{65}$	·13157	10	$\frac{37}{27}$	·13684	19	$\frac{25}{18}$	·14267	29	$\frac{69}{49}$	·14865	9
$\frac{65}{48}$	·13167	22	$\frac{85}{62}$	·13703	14	$\frac{82}{59}$	·14296	13	$\frac{100}{71}$	·14874	20
$\frac{42}{31}$	·13189	23	$\frac{48}{35}$	·13717	21	$\frac{57}{41}$	·14309	12	$\frac{31}{22}$	·14894	23

Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.
$\frac{86}{61}$	·14917	13	$\frac{10}{7}$	·15490	67	$\frac{42}{29}$	·16085	21	$\frac{69}{47}$	·16675	20
$\frac{55}{39}$	·14930	14	$\frac{93}{65}$	·15557	8	$\frac{71}{49}$	·16106	9	$\frac{47}{32}$	·16695	18
$\frac{79}{56}$	·14944	32	$\frac{83}{58}$	·15565	10	$\frac{100}{69}$	·16115	22	$\frac{72}{49}$	·16713	10
$\frac{24}{17}$	·14976	29	$\frac{73}{51}$	·15575	14	$\frac{29}{20}$	·16137	29	$\frac{97}{66}$	·16723	26
$\frac{89}{63}$	·15005	10	$\frac{63}{44}$	·15589	19	$\frac{74}{51}$	·16166	19	$\frac{25}{17}$	·16749	32
$\frac{65}{46}$	·15015	23	$\frac{53}{37}$	·15608	12	$\frac{45}{31}$	·16185	23	$\frac{78}{53}$	·16781	17
$\frac{41}{29}$	·15038	16	$\frac{96}{67}$	·15620	15	$\frac{61}{42}$	·16208	13	$\frac{53}{36}$	·16798	15
$\frac{99}{70}$	·15054	11	$\frac{43}{30}$	·15635	18	$\frac{77}{53}$	·16221	9	$\frac{81}{55}$	·16813	28
$\frac{58}{41}$	·15065	13	$\frac{76}{53}$	·15653	25	$\frac{93}{64}$	·16230	43	$\frac{28}{19}$	·16841	26
$\frac{75}{53}$	·15078	10	$\frac{33}{23}$	·15678	22	$\frac{16}{11}$	·16273	40	$\frac{87}{59}$	·16867	12
$\frac{92}{65}$	·15088	39	$\frac{89}{62}$	·15700	13	$\frac{99}{68}$	·16313	8	$\frac{59}{40}$	·16879	12
$\frac{17}{12}$	·15127	38	$\frac{56}{39}$	·15713	14	$\frac{83}{57}$	·16321	10	$\frac{90}{61}$	·16891	23
$\frac{95}{67}$	·15165	8	$\frac{79}{55}$	·15727	34	$\frac{67}{46}$	·16331	19	$\frac{31}{21}$	·16914	22
$\frac{78}{55}$	·15173	13	$\frac{23}{16}$	·15761	33	$\frac{51}{35}$	·16350	15	$\frac{96}{65}$	·16936	10
$\frac{61}{43}$	·15186	23	$\frac{82}{57}$	·15794	13	$\frac{86}{59}$	·16365	21	$\frac{65}{44}$	·16946	11
$\frac{44}{31}$	·15209	20	$\frac{59}{41}$	·15807	11	$\frac{35}{24}$	·16386	20	$\frac{99}{67}$	·16957	18
$\frac{71}{50}$	·15229	9	$\frac{95}{66}$	·15818	18	$\frac{89}{61}$	·16406	13	$\frac{34}{23}$	·16975	27
$\frac{98}{69}$	·15238	23	$\frac{36}{25}$	·15836	21	$\frac{54}{37}$	·16419	16	$\frac{71}{48}$	·17002	24
$\frac{27}{19}$	·15261	25	$\frac{85}{59}$	·15857	15	$\frac{73}{50}$	·16435	10	$\frac{37}{25}$	·17026	23
$\frac{91}{64}$	·15286	11	$\frac{49}{34}$	·15872	20	$\frac{92}{63}$	·16445	36	$\frac{77}{52}$	·17049	21
$\frac{64}{45}$	·15297	26	$\frac{62}{43}$	·15892	14	$\frac{19}{13}$	·16481	35	$\frac{40}{27}$	·17070	19
$\frac{37}{26}$	·15323	20	$\frac{75}{52}$	·15906	9	$\frac{98}{67}$	·16516	8	$\frac{83}{56}$	·17089	18
$\frac{84}{59}$	·15343	16	$\frac{88}{61}$	·15915	55	$\frac{79}{54}$	·16524	13	$\frac{43}{29}$	·17107	17
$\frac{47}{33}$	·15359	22	$\frac{13}{9}$	·15970	52	$\frac{60}{41}$	·16537	25	$\frac{89}{60}$	·17124	16
$\frac{57}{40}$	·15381	16	$\frac{94}{65}$	·16022	8	$\frac{41}{28}$	·16562	25	$\frac{46}{31}$	·17140	14
$\frac{67}{47}$	·15397	13	$\frac{81}{56}$	·16030	11	$\frac{63}{43}$	·16587	12	$\frac{95}{64}$	·17154	15
$\frac{77}{54}$	·15410	9	$\frac{68}{47}$	·16041	17	$\frac{85}{58}$	·16599	34	$\frac{49}{33}$	·17169	24
$\frac{87}{61}$	·15419	7	$\frac{55}{38}$	·16058	12	$\frac{22}{15}$	·16633	32	$\frac{52}{35}$	·17193	23
$\frac{97}{68}$	·15426	64	$\frac{97}{67}$	·16070	15	$\frac{91}{62}$	·16665	10	$\frac{55}{37}$	·17216	21

Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.
$\frac{58}{39}$	·17237	18	$\frac{59}{39}$	·17979	20	$\frac{23}{15}$	·18564	32	$\frac{95}{61}$	·19239	10
$\frac{61}{41}$	·17255	16	$\frac{56}{37}$	·17999	22	$\frac{89}{58}$	·18596	11	$\frac{81}{52}$	·19249	11
$\frac{64}{43}$	·17271	15	$\frac{53}{35}$	·18021	25	$\frac{66}{43}$	·18607	24	$\frac{67}{43}$	·19260	20
$\frac{67}{45}$	·17286	14	$\frac{50}{33}$	·18046	13	$\frac{43}{28}$	·18631	25	$\frac{53}{34}$	·19280	14
$\frac{70}{47}$	·17300	12	$\frac{97}{64}$	·18059	15	$\frac{63}{41}$	·18656	13	$\frac{92}{59}$	·19294	18
$\frac{73}{49}$	·17312	12	$\frac{47}{31}$	·18074	15	$\frac{83}{54}$	·18669	40	$\frac{39}{25}$	·19312	28
$\frac{76}{51}$	·17324	11	$\frac{91}{60}$	·18089	16	$\frac{20}{13}$	·18709	34	$\frac{64}{41}$	·19340	12
$\frac{79}{53}$	·17335	10	$\frac{44}{29}$	·18105	18	$\frac{97}{63}$	·18743	9	$\frac{89}{57}$	·19352	30
$\frac{82}{55}$	·17345	10	$\frac{85}{56}$	·18123	19	$\frac{77}{50}$	·18752	15	$\frac{25}{16}$	·19382	32
$\frac{85}{57}$	·17355	8	$\frac{41}{27}$	·18142	21	$\frac{57}{37}$	·18767	13	$\frac{86}{55}$	·19414	13
$\frac{88}{59}$	·17363	8	$\frac{79}{52}$	·18163	21	$\frac{94}{61}$	·18780	19	$\frac{61}{39}$	·19427	11
$\frac{91}{61}$	·17371	8	$\frac{38}{25}$	·18184	24	$\frac{37}{24}$	·18799	20	$\frac{97}{62}$	·19438	19
$\frac{94}{63}$	·17379	7	$\frac{73}{48}$	·18208	26	$\frac{91}{59}$	·18819	13	$\frac{36}{23}$	·19457	23
$\frac{97}{65}$	·17386	7	$\frac{35}{23}$	·18234	28	$\frac{54}{35}$	·18832	18	$\frac{83}{53}$	·19480	18
$\frac{100}{67}$	·17393	216	$\frac{67}{44}$	·18262	11	$\frac{71}{46}$	·18850	11	$\frac{47}{30}$	·19498	25
$\frac{3}{2}$	·17609	223	$\frac{99}{65}$	·18273	20	$\frac{88}{57}$	·18861	45	$\frac{58}{37}$	·19523	17
$\frac{98}{65}$	·17832	6	$\frac{32}{21}$	·18293	22	$\frac{17}{11}$	·18906	40	$\frac{69}{44}$	·19540	12
$\frac{95}{63}$	·17838	8	$\frac{93}{61}$	·18315	12	$\frac{99}{64}$	·18946	7	$\frac{80}{51}$	·19552	9
$\frac{92}{61}$	·17846	8	$\frac{61}{40}$	·18327	12	$\frac{82}{53}$	·18953	13	$\frac{91}{58}$	·19561	68
$\frac{89}{59}$	·17854	9	$\frac{90}{59}$	·18339	26	$\frac{65}{42}$	·18966	22	$\frac{11}{7}$	·19629	65
$\frac{86}{57}$	·17863	9	$\frac{29}{19}$	·18365	27	$\frac{48}{31}$	·18988	18	$\frac{96}{61}$	·19694	9
$\frac{83}{55}$	·17872	9	$\frac{84}{55}$	·18392	14	$\frac{79}{51}$	·19006	27	$\frac{85}{54}$	·19703	10
$\frac{80}{53}$	·17881	11	$\frac{55}{36}$	·18406	15	$\frac{31}{20}$	·19033	28	$\frac{74}{47}$	·19713	15
$\frac{77}{51}$	·17892	11	$\frac{81}{53}$	·18421	31	$\frac{76}{49}$	·19061	20	$\frac{63}{40}$	·19728	21
$\frac{74}{49}$	·17903	13	$\frac{26}{17}$	·18452	34	$\frac{45}{29}$	·19081	26	$\frac{52}{33}$	·19749	14
$\frac{71}{47}$	·17916	14	$\frac{75}{49}$	·18486	19	$\frac{59}{38}$	·19107	15	$\frac{93}{59}$	·19763	18
$\frac{68}{45}$	·17930	14	$\frac{49}{32}$	·18505	18	$\frac{73}{47}$	·19122	11	$\frac{41}{26}$	·19781	24
$\frac{65}{43}$	·17944	17	$\frac{72}{47}$	·18523	10	$\frac{87}{56}$	·19133	56	$\frac{71}{45}$	·19805	32
$\frac{62}{41}$	·17961	18	$\frac{95}{62}$	·18533	31	$\frac{14}{9}$	·19189	50	$\frac{30}{19}$	·19837	29

Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.
$\frac{79}{50}$	·19866	18	$\frac{69}{43}$	·20538	17	$\frac{70}{43}$	·21163	17	$\frac{81}{49}$	·21829	21
$\frac{49}{31}$	·19884	20	$\frac{61}{38}$	·20555	22	$\frac{57}{35}$	·21180	29	$\frac{43}{26}$	·21850	18
$\frac{68}{43}$	·19904	12	$\frac{53}{33}$	·20577	13	$\frac{44}{27}$	·21209	21	$\frac{91}{55}$	·21868	16
$\frac{87}{55}$	·19916	41	$\frac{98}{61}$	·20590	15	$\frac{75}{46}$	·21230	31	$\frac{48}{29}$	·21884	29
$\frac{19}{12}$	·19957	43	$\frac{45}{28}$	·20605	19	$\frac{31}{19}$	·21261	28	$\frac{53}{32}$	·21913	23
$\frac{84}{53}$	·20000	13	$\frac{82}{51}$	·20624	23	$\frac{80}{49}$	·21289	19	$\frac{58}{35}$	·21936	20
$\frac{65}{41}$	·20013	23	$\frac{37}{23}$	·20647	29	$\frac{49}{30}$	·21308	21	$\frac{63}{38}$	·21956	17
$\frac{46}{29}$	·20036	20	$\frac{66}{41}$	·20676	11	$\frac{67}{41}$	·21329	13	$\frac{68}{41}$	·21973	14
$\frac{73}{46}$	·20056	10	$\frac{95}{59}$	·20687	26	$\frac{85}{52}$	·21342	46	$\frac{73}{44}$	·21987	12
$\frac{100}{63}$	·20066	25	$\frac{29}{18}$	·20713	30	$\frac{18}{11}$	·21388	41	$\frac{78}{47}$	·21999	12
$\frac{27}{17}$	·20091	29	$\frac{79}{49}$	·20743	18	$\frac{95}{58}$	·21429	10	$\frac{83}{50}$	·22011	9
$\frac{89}{56}$	·20120	13	$\frac{50}{31}$	·20761	20	$\frac{77}{47}$	·21439	16	$\frac{88}{53}$	·22020	9
$\frac{62}{39}$	·20133	11	$\frac{71}{44}$	·20781	11	$\frac{59}{36}$	·21455	12	$\frac{93}{56}$	·22029	9
$\frac{97}{61}$	·20144	21	$\frac{92}{57}$	·20792	36	$\frac{100}{61}$	·21467	17	$\frac{98}{59}$	·22038	147
$\frac{35}{22}$	·20165	24	$\frac{21}{13}$	·20828	34	$\frac{41}{25}$	·21484	28	$\frac{5}{3}$	·22185	149
$\frac{78}{49}$	·20189	22	$\frac{97}{60}$	·20862	9	$\frac{64}{39}$	·21512	12	$\frac{97}{58}$	·22334	9
$\frac{43}{27}$	·20211	17	$\frac{76}{47}$	·20871	17	$\frac{87}{53}$	·21524	36	$\frac{92}{55}$	·22343	9
$\frac{94}{59}$	·20228	14	$\frac{55}{34}$	·20888	15	$\frac{23}{14}$	·21560	32	$\frac{87}{52}$	·22352	9
$\frac{51}{32}$	·20242	23	$\frac{89}{55}$	·20903	23	$\frac{97}{59}$	·21592	10	$\frac{82}{49}$	·22361	12
$\frac{59}{37}$	·20265	17	$\frac{34}{21}$	·20926	26	$\frac{74}{45}$	·21602	19	$\frac{77}{46}$	·22373	13
$\frac{67}{42}$	·20282	14	$\frac{81}{50}$	·20952	18	$\frac{51}{31}$	·21621	18	$\frac{72}{43}$	·22386	15
$\frac{75}{47}$	·20296	12	$\frac{47}{29}$	·20970	25	$\frac{79}{48}$	·21639	32	$\frac{67}{40}$	·22401	18
$\frac{83}{52}$	·20308	9	$\frac{60}{37}$	·20995	16	$\frac{28}{17}$	·21671	29	$\frac{62}{37}$	·22419	20
$\frac{91}{57}$	·20317	8	$\frac{73}{45}$	·21011	11	$\frac{89}{54}$	·21700	13	$\frac{57}{34}$	·22439	25
$\frac{99}{62}$	·20325	87	$\frac{86}{53}$	·21022	9	$\frac{61}{37}$	·21713	13	$\frac{52}{31}$	·22464	15
$\frac{8}{5}$	·20412	93	$\frac{99}{61}$	·21031	54	$\frac{94}{57}$	·21726	22	$\frac{99}{59}$	·22479	15
$\frac{93}{58}$	·20505	9	$\frac{13}{8}$	·21085	57	$\frac{33}{20}$	·21748	31	$\frac{47}{28}$	·22494	17
$\frac{85}{53}$	·20514	11	$\frac{96}{59}$	·21142	9	$\frac{71}{43}$	·21779	26	$\frac{89}{53}$	·22511	20
$\frac{77}{48}$	·20525	13	$\frac{83}{51}$	·21151	12	$\frac{38}{23}$	·21805	24	$\frac{42}{25}$	·22531	22

Vulgar Fraction	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.
$\frac{79}{47}$	·22553	25	$\frac{70}{41}$	·23232	25	$\frac{92}{53}$	·23951	25	$\frac{83}{47}$	·24698	18
$\frac{37}{22}$	·22578	29	$\frac{41}{24}$	·23257	20	$\frac{33}{19}$	·23976	31	$\frac{53}{30}$	·24716	18
$\frac{69}{41}$	·22607	33	$\frac{94}{55}$	·23277	15	$\frac{73}{42}$	·24007	26	$\frac{76}{43}$	·24734	11
$\frac{32}{19}$	·22640	25	$\frac{53}{31}$	·23292	21	$\frac{40}{23}$	·24033	22	$\frac{99}{56}$	·24745	34
$\frac{91}{54}$	·22665	13	$\frac{65}{38}$	·23313	15	$\frac{87}{50}$	·24055	19	$\frac{23}{13}$	·24779	39
$\frac{59}{35}$	·22678	15	$\frac{77}{45}$	·23328	11	$\frac{47}{27}$	·24074	29	$\frac{85}{48}$	·24818	14
$\frac{86}{51}$	·22693	31	$\frac{89}{52}$	·23339	69	$\frac{54}{31}$	·24103	23	$\frac{62}{35}$	·24832	32
$\frac{27}{16}$	·22724	36	$\frac{12}{7}$	·23408	68	$\frac{61}{35}$	·24126	19	$\frac{39}{22}$	·24864	21
$\frac{76}{45}$	·22760	20	$\frac{91}{53}$	·23476	11	$\frac{68}{39}$	·24145	14	$\frac{94}{53}$	·24885	15
$\frac{49}{29}$	·22780	21	$\frac{79}{46}$	·23487	14	$\frac{75}{43}$	·24159	12	$\frac{55}{31}$	·24900	20
$\frac{71}{42}$	·22801	11	$\frac{67}{39}$	·23501	20	$\frac{82}{47}$	·24171	11	$\frac{71}{40}$	·24920	12
$\frac{93}{55}$	·22812	36	$\frac{55}{32}$	·23521	15	$\frac{89}{51}$	·24182	9	$\frac{87}{49}$	·24932	56
$\frac{22}{13}$	·22848	40	$\frac{98}{57}$	·23536	17	$\frac{96}{55}$	·24191	113	$\frac{16}{9}$	·24988	54
$\frac{83}{49}$	·22888	15	$\frac{43}{25}$	·23553	23	$\frac{7}{4}$	·24304	109	$\frac{89}{50}$	·25042	12
$\frac{61}{36}$	·22903	12	$\frac{74}{43}$	·23576	33	$\frac{100}{57}$	·24413	7	$\frac{73}{41}$	·25054	18
$\frac{100}{59}$	·22915	18	$\frac{31}{18}$	·23609	30	$\frac{93}{53}$	·24420	10	$\frac{57}{32}$	·25072	15
$\frac{39}{23}$	·22933	20	$\frac{81}{47}$	·23639	18	$\frac{86}{49}$	·24430	12	$\frac{98}{55}$	·25087	18
$\frac{95}{56}$	·22953	15	$\frac{50}{29}$	·23657	22	$\frac{79}{45}$	·24442	13	$\frac{41}{23}$	·25105	29
$\frac{56}{33}$	·22968	17	$\frac{69}{40}$	·23679	12	$\frac{72}{41}$	·24455	16	$\frac{66}{37}$	·25134	13
$\frac{73}{43}$	·22985	11	$\frac{88}{51}$	·23691	45	$\frac{65}{37}$	·24471	21	$\frac{91}{51}$	·25147	34
$\frac{90}{53}$	·22996	49	$\frac{19}{11}$	·23736	48	$\frac{58}{33}$	·24492	25	$\frac{25}{14}$	·25181	37
$\frac{17}{10}$	·23045	45	$\frac{83}{48}$	·23784	14	$\frac{51}{29}$	·24517	16	$\frac{84}{47}$	·25218	16
$\frac{97}{57}$	·23090	9	$\frac{64}{37}$	·23798	26	$\frac{95}{54}$	·24533	18	$\frac{59}{33}$	·25234	14
$\frac{80}{47}$	·23099	15	$\frac{45}{26}$	·23824	24	$\frac{44}{25}$	·24551	22	$\frac{93}{52}$	·25248	25
$\frac{63}{37}$	·23114	26	$\frac{71}{41}$	·23848	10	$\frac{81}{46}$	·24573	25	$\frac{34}{19}$	·25273	29
$\frac{46}{27}$	·23140	21	$\frac{97}{56}$	·23858	30	$\frac{37}{21}$	·24598	31	$\frac{77}{43}$	·25302	24
$\frac{75}{44}$	·23161	34	$\frac{26}{15}$	·23888	34	$\frac{67}{38}$	·24629	12	$\frac{43}{24}$	·25326	18
$\frac{29}{17}$	·23195	26	$\frac{85}{49}$	·23922	15	$\frac{97}{55}$	·24641	26	$\frac{95}{53}$	·25344	16
$\frac{99}{58}$	·23221	11	$\frac{59}{34}$	·23937	14	$\frac{30}{17}$	·24667	31	$\frac{52}{29}$	·25360	25

Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.
$\frac{61}{34}$	·25385	19	$\frac{95}{52}$	·26172	16	$\frac{80}{43}$	·26962	15	$\frac{89}{47}$	·27729	26
$\frac{70}{39}$	·25404	14	$\frac{53}{29}$	·26188	23	$\frac{67}{36}$	·26977	22	$\frac{36}{19}$	·27755	25
$\frac{79}{44}$	·25418	10	$\frac{64}{35}$	·26211	17	$\frac{54}{29}$	·26999	16	$\frac{91}{48}$	·27780	16
$\frac{88}{49}$	·25428	10	$\frac{75}{41}$	·26228	12	$\frac{95}{51}$	·27015	21	$\frac{55}{29}$	·27796	21
$\frac{97}{54}$	·25438	89	$\frac{86}{47}$	·26240	9	$\frac{41}{22}$	·27036	29	$\frac{74}{39}$	·27817	11
$\frac{9}{5}$	·25527	95	$\frac{97}{53}$	·26249	75	$\frac{69}{37}$	·27065	12	$\frac{93}{49}$	·27828	47
$\frac{92}{51}$	·25622	10	$\frac{11}{6}$	·26324	80	$\frac{97}{52}$	·27077	30	$\frac{19}{10}$	·27875	45
$\frac{83}{46}$	·25632	13	$\frac{90}{49}$	·26404	12	$\frac{28}{15}$	·27107	29	$\frac{97}{51}$	·27920	11
$\frac{74}{41}$	·25645	16	$\frac{79}{43}$	·26416	15	$\frac{99}{53}$	·27136	12	$\frac{78}{41}$	·27931	18
$\frac{65}{36}$	·25661	22	$\frac{68}{37}$	·26431	20	$\frac{71}{38}$	·27148	26	$\frac{59}{31}$	·27949	15
$\frac{56}{31}$	·25683	30	$\frac{57}{31}$	·26451	31	$\frac{43}{23}$	·27174	33	$\frac{99}{52}$	·27964	20
$\frac{47}{26}$	·25713	19	$\frac{46}{25}$	·26482	22	$\frac{58}{31}$	·27207	19	$\frac{40}{21}$	·27984	34
$\frac{85}{47}$	·25732	24	$\frac{81}{44}$	·26504	28	$\frac{73}{39}$	·27226	12	$\frac{61}{32}$	·28018	16
$\frac{38}{21}$	·25756	31	$\frac{35}{19}$	·26532	24	$\frac{88}{47}$	·27238	62	$\frac{82}{43}$	·28034	49
$\frac{67}{37}$	·25787	12	$\frac{94}{51}$	·26556	14	$\frac{15}{8}$	·27300	59	$\frac{21}{11}$	·28083	46
$\frac{96}{53}$	·25799	29	$\frac{59}{32}$	·26570	17	$\frac{92}{49}$	·27359	12	$\frac{86}{45}$	·28129	14
$\frac{29}{16}$	·25828	34	$\frac{83}{45}$	·26587	40	$\frac{77}{41}$	·27371	17	$\frac{65}{34}$	·28143	29
$\frac{78}{43}$	·25862	22	$\frac{24}{13}$	·26627	39	$\frac{62}{33}$	·27388	28	$\frac{44}{23}$	·28172	28
$\frac{49}{27}$	·25884	23	$\frac{85}{46}$	·26666	16	$\frac{47}{25}$	·27416	22	$\frac{67}{35}$	·28200	14
$\frac{69}{38}$	·25907	12	$\frac{61}{33}$	·26682	13	$\frac{79}{42}$	·27438	32	$\frac{90}{47}$	·28214	41
$\frac{89}{49}$	·25919	45	$\frac{98}{53}$	·26695	22	$\frac{32}{17}$	·27470	32	$\frac{23}{12}$	·28255	38
$\frac{20}{11}$	·25964	43	$\frac{37}{20}$	·26717	25	$\frac{81}{43}$	·27502	21	$\frac{94}{49}$	·28293	13
$\frac{91}{50}$	·26007	13	$\frac{87}{47}$	·26742	19	$\frac{49}{26}$	·27523	24	$\frac{71}{37}$	·28306	24
$\frac{71}{39}$	·26020	21	$\frac{50}{27}$	·26761	25	$\frac{66}{35}$	·27547	16	$\frac{48}{25}$	·28330	24
$\frac{51}{28}$	·26041	19	$\frac{63}{34}$	·26786	17	$\frac{83}{44}$	·27563	9	$\frac{73}{38}$	·28354	12
$\frac{82}{45}$	·26060	31	$\frac{76}{41}$	·26803	12	$\frac{100}{53}$	·27572	49	$\frac{98}{51}$	·28366	34
$\frac{31}{17}$	·26091	35	$\frac{89}{48}$	·26815	69	$\frac{17}{9}$	·27621	55	$\frac{25}{13}$	·28400	43
$\frac{73}{40}$	·26126	26	$\frac{13}{7}$	·26884	67	$\frac{87}{46}$	·27676	14	$\frac{77}{40}$	·28443	21
$\frac{42}{23}$	·26152	20	$\frac{93}{50}$	·26951	11	$\frac{70}{37}$	·27690	22	$\frac{52}{27}$	·28464	21
						$\frac{53}{28}$	·27712	17			

Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.
$\frac{79}{41}$	·28485	38	$\frac{49}{25}$	·29226	17	$\frac{95}{47}$	·30562	10	$\frac{88}{43}$	·31101	24
$\frac{27}{14}$	·28523	38	$\frac{100}{51}$	·29243	17	$\frac{93}{46}$	·30572	11	$\frac{43}{21}$	·31125	25
$\frac{83}{43}$	·28561	18	$\frac{51}{26}$	·29260	32	$\frac{91}{45}$	·30583	11	$\frac{84}{41}$	·31150	25
$\frac{56}{29}$	·28579	18	$\frac{53}{27}$	·29292	28	$\frac{89}{44}$	·30594	11	$\frac{41}{20}$	·31175	28
$\frac{85}{44}$	·28597	34	$\frac{55}{28}$	·29320	27	$\frac{87}{43}$	·30605	12	$\frac{80}{39}$	·31203	28
$\frac{29}{15}$	·28631	32	$\frac{57}{29}$	·29347	26	$\frac{85}{42}$	·30617	13	$\frac{39}{19}$	·31231	30
$\frac{89}{46}$	·28663	16	$\frac{59}{30}$	·29373	24	$\frac{83}{41}$	·30630	13	$\frac{76}{37}$	·31261	32
$\frac{60}{31}$	·28679	15	$\frac{61}{31}$	·29397	22	$\frac{81}{40}$	·39643	14	$\frac{37}{18}$	·31293	33
$\frac{91}{47}$	·28694	30	$\frac{63}{32}$	·29419	21	$\frac{79}{39}$	·30657	14	$\frac{72}{35}$	·31326	36
$\frac{31}{16}$	·28724	28	$\frac{65}{33}$	·29440	19	$\frac{77}{38}$	·30671	15	$\frac{35}{17}$	·31362	38
$\frac{95}{49}$	·28752	15	$\frac{67}{34}$	·29459	19	$\frac{75}{37}$	·30686	16	$\frac{68}{33}$	·31400	39
$\frac{64}{33}$	·28767	13	$\frac{69}{35}$	·29478	18	$\frac{73}{36}$	·30702	17	$\frac{33}{16}$	·31439	28
$\frac{97}{50}$	·28780	26	$\frac{71}{36}$	·29496	16	$\frac{71}{35}$	·30719	18	$\frac{97}{47}$	·31467	15
$\frac{33}{17}$	·28806	41	$\frac{73}{37}$	·29512	16	$\frac{69}{34}$	·30737	19	$\frac{64}{31}$	·31482	14
$\frac{68}{35}$	·28847	33	$\frac{75}{38}$	·29528	15	$\frac{67}{33}$	·30756	20	$\frac{95}{46}$	·31496	31
$\frac{35}{18}$	·28880	33	$\frac{77}{39}$	·29543	14	$\frac{65}{32}$	·30776	22	$\frac{31}{15}$	·31527	32
$\frac{72}{37}$	·28913	32	$\frac{79}{40}$	·29557	14	$\frac{63}{31}$	·30798	23	$\frac{91}{44}$	·31559	16
$\frac{37}{19}$	·28945	30	$\frac{81}{41}$	·29571	12	$\frac{61}{30}$	·30821	24	$\frac{60}{29}$	·31575	17
$\frac{76}{39}$	·28975	28	$\frac{83}{42}$	·29583	12	$\frac{59}{29}$	·30845	26	$\frac{89}{43}$	·31592	35
$\frac{39}{20}$	·29003	28	$\frac{85}{43}$	·29595	12	$\frac{57}{28}$	·30871	29	$\frac{29}{14}$	·31627	37
$\frac{80}{41}$	·29031	25	$\frac{87}{44}$	·29607	11	$\frac{55}{27}$	·30900	31	$\frac{85}{41}$	·31664	19
$\frac{41}{21}$	·29056	25	$\frac{89}{45}$	·29618	10	$\frac{53}{26}$	·30931	32	$\frac{56}{27}$	·31683	19
$\frac{84}{43}$	·29081	24	$\frac{91}{46}$	·29628	10	$\frac{51}{25}$	·30963	17	$\frac{83}{40}$	·31702	40
$\frac{43}{22}$	·29105	22	$\frac{93}{47}$	·29638	10	$\frac{100}{49}$	·30980	19	$\frac{27}{13}$	·31742	43
$\frac{88}{45}$	·29127	21	$\frac{95}{48}$	·29648	9	$\frac{49}{24}$	·30999	18	$\frac{79}{38}$	·31785	21
$\frac{45}{23}$	·29148	21	$\frac{97}{49}$	·29657	10	$\frac{96}{47}$	·31017	20	$\frac{52}{25}$	·31806	23
$\frac{92}{47}$	·29169	20	$\frac{99}{50}$	·29667	436	$\frac{47}{23}$	·31037	21	$\frac{77}{37}$	·31829	47
$\frac{47}{24}$	·29189	18	$\frac{2}{1}$	·30103	441	$\frac{92}{45}$	·31058	21	$\frac{25}{12}$	·31876	37
$\frac{96}{49}$	·29207	19	$\frac{99}{49}$	·30544	9	$\frac{45}{22}$	·31079	22	$\frac{98}{47}$	·31913	12
			$\frac{97}{48}$	·30553	9						

Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.
$\frac{73}{35}$	·31925	26	$\frac{100}{47}$	·32790	12	$\frac{76}{35}$	·33674	20	$\frac{82}{37}$	·34561	2
$\frac{48}{23}$	·31951	27	$\frac{83}{39}$	·32802	16	$\frac{63}{29}$	·33694	30	$\frac{51}{23}$	·34584	27
$\frac{71}{34}$	·31978	13	$\frac{66}{31}$	·32818	29	$\frac{50}{23}$	·33724	22	$\frac{71}{32}$	·34611	15
$\frac{94}{45}$	·31991	43	$\frac{49}{23}$	·32847	24	$\frac{87}{40}$	·33746	29	$\frac{91}{41}$	·34626	53
$\frac{23}{11}$	·32034	43	$\frac{81}{38}$	·32871	35	$\frac{37}{17}$	·33775	27	$\frac{20}{9}$	·34679	54
$\frac{90}{43}$	·32077	15	$\frac{32}{15}$	·32906	37	$\frac{98}{45}$	·33802	15	$\frac{89}{40}$	·34733	16
$\frac{67}{32}$	·32092	31	$\frac{79}{37}$	·32943	25	$\frac{61}{28}$	·33817	19	$\frac{69}{31}$	·34749	29
$\frac{44}{21}$	·32123	32	$\frac{47}{22}$	·32968	31	$\frac{85}{39}$	·33836	46	$\frac{49}{22}$	·34778	24
$\frac{65}{31}$	·32155	17	$\frac{62}{29}$	·32999	20	$\frac{24}{11}$	·33882	48	$\frac{78}{35}$	·34802	44
$\frac{86}{41}$	·32172	50	$\frac{77}{36}$	·33019	13	$\frac{83}{38}$	·33930	19	$\frac{29}{13}$	·34846	34
$\frac{21}{10}$	·32222	53	$\frac{92}{43}$	·33032	67	$\frac{59}{27}$	·33949	16	$\frac{96}{43}$	·34880	15
$\frac{82}{39}$	·32275	18	$\frac{15}{7}$	·33099	71	$\frac{94}{43}$	·33965	30	$\frac{67}{30}$	·34895	38
$\frac{61}{29}$	·32293	38	$\frac{88}{41}$	·33170	14	$\frac{35}{16}$	·33995	34	$\frac{38}{17}$	·34933	31
$\frac{40}{19}$	·32331	23	$\frac{73}{34}$	·33184	23	$\frac{81}{37}$	·34029	25	$\frac{85}{38}$	·34964	24
$\frac{99}{47}$	·32354	15	$\frac{58}{27}$	·33207	37	$\frac{46}{21}$	·34054	36	$\frac{47}{21}$	·34988	37
$\frac{59}{28}$	·32369	20	$\frac{43}{20}$	·33244	31	$\frac{57}{26}$	·34090	25	$\frac{56}{25}$	·35025	26
$\frac{78}{37}$	·32389	12	$\frac{71}{33}$	·33275	13	$\frac{68}{31}$	·34115	18	$\frac{65}{29}$	·35051	21
$\frac{97}{46}$	·32401	50	$\frac{99}{46}$	·33288	34	$\frac{79}{36}$	·34133	13	$\frac{74}{33}$	·35072	16
$\frac{19}{9}$	·32451	52	$\frac{28}{13}$	·33322	34	$\frac{90}{41}$	·34146	96	$\frac{83}{37}$	·35088	13
$\frac{93}{44}$	·32503	13	$\frac{97}{45}$	·33356	14	$\frac{11}{5}$	·34242	90	$\frac{92}{41}$	·35101	117
$\frac{74}{35}$	·32516	23	$\frac{69}{32}$	·33370	33	$\frac{97}{44}$	·34332	12	$\frac{9}{4}$	·35218	112
$\frac{55}{26}$	·32539	18	$\frac{41}{19}$	·33403	24	$\frac{86}{39}$	·34344	14	$\frac{97}{43}$	·35330	12
$\frac{91}{43}$	·32557	28	$\frac{95}{44}$	·33427	18	$\frac{75}{34}$	·34358	20	$\frac{88}{39}$	·35342	14
$\frac{36}{17}$	·32585	29	$\frac{54}{25}$	·33445	26	$\frac{64}{29}$	·34378	29	$\frac{79}{35}$	·35356	18
$\frac{89}{42}$	·32614	20	$\frac{67}{31}$	·33471	18	$\frac{53}{24}$	·34407	18	$\frac{70}{31}$	·35374	23
$\frac{53}{25}$	·32634	25	$\frac{80}{37}$	·33489	12	$\frac{95}{43}$	·34425	25	$\frac{61}{27}$	·35397	30
$\frac{70}{33}$	·32659	15	$\frac{93}{43}$	·33501	78	$\frac{42}{19}$	·34450	31	$\frac{52}{23}$	·35427	20
$\frac{87}{41}$	·32674	62	$\frac{13}{6}$	·33579	82	$\frac{73}{33}$	·34481	42	$\frac{95}{42}$	·35447	25
$\frac{17}{8}$	·32736	54	$\frac{89}{41}$	·33661	13	$\frac{31}{14}$	·34523	38	$\frac{43}{19}$	·35472	29

Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.
$\frac{77}{34}$	·35501	38	$\frac{37}{16}$	·36408	34	$\frac{97}{41}$	·37399	15	$\frac{46}{19}$	·38401	36
$\frac{34}{15}$	·35539	31	$\frac{81}{35}$	·36442	28	$\frac{71}{30}$	·37414	32	$\frac{63}{26}$	·38437	21
$\frac{93}{41}$	·35570	18	$\frac{44}{19}$	·36470	24	$\frac{45}{19}$	·37446	36	$\frac{80}{33}$	·38458	13
$\frac{59}{26}$	·35588	20	$\frac{95}{41}$	·36494	21	$\frac{64}{27}$	·37482	19	$\frac{97}{40}$	·38471	64
$\frac{84}{37}$	·35608	47	$\frac{51}{22}$	·36515	34	$\frac{83}{35}$	·37501	65	$\frac{17}{7}$	·38535	69
$\frac{25}{11}$	·35655	43	$\frac{58}{25}$	·36549	26	$\frac{19}{8}$	·37566	62	$\frac{90}{37}$	·38604	16
$\frac{91}{40}$	·35698	16	$\frac{65}{28}$	·36575	22	$\frac{88}{37}$	·37628	17	$\frac{73}{30}$	·38620	26
$\frac{66}{29}$	·35714	37	$\frac{72}{31}$	·36597	18	$\frac{69}{29}$	·37645	30	$\frac{56}{23}$	·38646	20
$\frac{41}{18}$	·35751	25	$\frac{79}{34}$	·36615	15	$\frac{50}{21}$	·37675	26	$\frac{95}{39}$	·38666	28
$\frac{98}{43}$	·35776	17	$\frac{86}{37}$	·36630	12	$\frac{81}{34}$	·37701	41	$\frac{39}{16}$	·38694	28
$\frac{57}{25}$	·35793	24	$\frac{93}{40}$	·36642	11	$\frac{31}{13}$	·37742	45	$\frac{100}{41}$	·38722	17
$\frac{73}{32}$	·35817	16	$\frac{100}{43}$	·36653	145	$\frac{74}{31}$	·37787	33	$\frac{61}{25}$	·38739	21
$\frac{89}{39}$	·35833	69	$\frac{7}{3}$	·36798	151	$\frac{43}{18}$	·37820	25	$\frac{83}{34}$	·38760	58
$\frac{16}{7}$	·35902	72	$\frac{96}{41}$	·36949	12	$\frac{98}{41}$	·37845	18	$\frac{22}{9}$	·38818	52
$\frac{87}{38}$	·35974	16	$\frac{89}{38}$	·36961	13	$\frac{55}{23}$	·37863	28	$\frac{93}{38}$	·38870	16
$\frac{71}{31}$	·35990	25	$\frac{82}{35}$	·36974	17	$\frac{67}{28}$	·37891	21	$\frac{71}{29}$	·38886	31
$\frac{55}{24}$	·36015	20	$\frac{75}{32}$	·36991	20	$\frac{79}{33}$	·37912	14	$\frac{49}{20}$	·38917	28
$\frac{94}{41}$	·36035	26	$\frac{68}{29}$	·37011	25	$\frac{91}{38}$	·37926	95	$\frac{76}{31}$	·38945	52
$\frac{39}{17}$	·36061	42	$\frac{61}{26}$	·37036	30	$\frac{12}{5}$	·38021	98	$\frac{27}{11}$	·38997	46
$\frac{62}{27}$	·36103	19	$\frac{54}{23}$	·37066	41	$\frac{89}{37}$	·38119	15	$\frac{86}{35}$	·39043	21
$\frac{85}{37}$	·36122	51	$\frac{47}{20}$	·37107	25	$\frac{77}{32}$	·38134	21	$\frac{59}{24}$	·39064	20
$\frac{23}{10}$	·36173	44	$\frac{87}{37}$	·37132	29	$\frac{65}{27}$	·38155	31	$\frac{91}{37}$	·39084	37
$\frac{99}{43}$	·36217	13	$\frac{40}{17}$	·37161	35	$\frac{53}{22}$	·38186	21	$\frac{32}{13}$	·39121	48
$\frac{76}{33}$	·36230	25	$\frac{73}{31}$	·37196	42	$\frac{94}{39}$	·38207	26	$\frac{69}{28}$	·39169	42
$\frac{53}{23}$	·36255	23	$\frac{33}{14}$	·37238	35	$\frac{41}{17}$	·38233	37	$\frac{37}{15}$	·39211	37
$\frac{83}{36}$	·36278	40	$\frac{92}{39}$	·37273	18	$\frac{70}{29}$	·38270	16	$\frac{79}{32}$	·39248	32
$\frac{30}{13}$	·36318	34	$\frac{59}{25}$	·37291	21	$\frac{99}{41}$	·38286	36	$\frac{42}{17}$	·39280	29
$\frac{97}{42}$	·36352	15	$\frac{85}{36}$	·37312	46	$\frac{29}{12}$	·38322	48	$\frac{89}{36}$	·29309	26
$\frac{67}{29}$	·36367	41	$\frac{26}{11}$	·37358	41	$\frac{75}{31}$	·38370	31	$\frac{47}{19}$	·39335	23

Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.
$\frac{99}{40}$	·39358	20	$\frac{94}{37}$	·40493	19	$\frac{99}{38}$	·41586	13	$\frac{8}{3}$	·42597	147
$\frac{52}{21}$	·39378	36	$\frac{61}{24}$	·40512	20	$\frac{86}{33}$	·41599	17	$\frac{99}{37}$	·42744	12
$\frac{57}{23}$	·39414	31	$\frac{89}{35}$	·40532	45	$\frac{73}{28}$	·41616	26	$\frac{91}{34}$	·42756	16
$\frac{62}{25}$	·39445	26	$\frac{28}{11}$	·40577	50	$\frac{60}{23}$	·41642	41	$\frac{83}{31}$	·42772	18
$\frac{67}{27}$	·39471	22	$\frac{79}{31}$	·40627	27	$\frac{47}{18}$	·41683	30	$\frac{75}{28}$	·42790	23
$\frac{72}{29}$	·39493	20	$\frac{51}{20}$	·40654	29	$\frac{81}{31}$	·41713	41	$\frac{67}{25}$	·42813	30
$\frac{77}{31}$	·39513	17	$\frac{74}{29}$	·40683	16	$\frac{34}{13}$	·41754	37	$\frac{59}{22}$	·42843	39
$\frac{82}{33}$	·39530	15	$\frac{97}{38}$	·40699	50	$\frac{89}{34}$	·41791	23	$\frac{51}{19}$	·42882	24
$\frac{87}{35}$	·39545	14	$\frac{23}{9}$	·40749	55	$\frac{55}{21}$	·41814	27	$\frac{94}{35}$	·42906	29
$\frac{92}{37}$	·39559	12	$\frac{87}{34}$	·40804	20	$\frac{76}{29}$	·41841	16	$\frac{43}{16}$	·42935	34
$\frac{97}{39}$	·39571	223	$\frac{64}{25}$	·40824	42	$\frac{97}{37}$	·41857	56	$\frac{78}{29}$	·42969	44
$\frac{5}{2}$	·39794	223	$\frac{41}{16}$	·40866	28	$\frac{21}{8}$	·41913	59	$\frac{35}{13}$	·43013	34
$\frac{98}{39}$	·40017	11	$\frac{100}{39}$	·40894	18	$\frac{92}{35}$	·41972	18	$\frac{97}{36}$	·43047	19
$\frac{93}{37}$	·40028	13	$\frac{59}{23}$	·40912	25	$\frac{71}{27}$	·41990	32	$\frac{62}{23}$	·43066	22
$\frac{88}{35}$	·40041	16	$\frac{77}{30}$	·40937	15	$\frac{50}{19}$	·42022	29	$\frac{89}{33}$	·43088	48
$\frac{83}{33}$	·40057	16	$\frac{95}{37}$	·40952	65	$\frac{79}{30}$	·42051	50	$\frac{27}{10}$	·43136	44
$\frac{78}{31}$	·40073	19	$\frac{18}{7}$	·41017	74	$\frac{29}{11}$	·42101	41	$\frac{100}{37}$	·43180	16
$\frac{73}{29}$	·40092	23	$\frac{85}{33}$	·41091	19	$\frac{95}{36}$	·42142	18	$\frac{73}{27}$	·43196	35
$\frac{68}{27}$	·40115	25	$\frac{67}{26}$	·41110	35	$\frac{66}{25}$	·42160	47	$\frac{46}{17}$	·43231	39
$\frac{63}{25}$	·40140	30	$\frac{49}{19}$	·41145	28	$\frac{37}{14}$	·42207	38	$\frac{65}{24}$	·43270	22
$\frac{58}{23}$	·40170	36	$\frac{80}{31}$	·41173	45	$\frac{82}{31}$	·42245	31	$\frac{84}{31}$	·43292	73
$\frac{53}{21}$	·40206	43	$\frac{31}{12}$	·41218	48	$\frac{45}{17}$	·42276	27	$\frac{19}{7}$	·43365	72
$\frac{48}{19}$	·40249	25	$\frac{75}{29}$	·41266	34	$\frac{98}{37}$	·42303	22	$\frac{87}{32}$	·43437	20
$\frac{91}{36}$	·40274	28	$\frac{44}{17}$	·41300	45	$\frac{53}{20}$	·42325	35	$\frac{68}{25}$	·43457	36
$\frac{43}{17}$	·40302	32	$\frac{57}{22}$	·41345	29	$\frac{61}{23}$	·42360	28	$\frac{49}{18}$	·43493	30
$\frac{81}{32}$	·40334	35	$\frac{70}{27}$	·41374	19	$\frac{69}{26}$	·42388	21	$\frac{79}{29}$	·43523	50
$\frac{38}{15}$	·40369	41	$\frac{83}{32}$	·41393	14	$\frac{77}{29}$	·42409	18	$\frac{30}{11}$	·43573	56
$\frac{71}{28}$	·40410	47	$\frac{96}{37}$	·41407	90	$\frac{85}{32}$	·42427	14	$\frac{71}{26}$	·43629	40
$\frac{33}{13}$	·40457	36	$\frac{13}{5}$	·41497	89	$\frac{93}{35}$	·42441	156	$\frac{41}{15}$	·43669	31

Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.
$\frac{93}{34}$	·43700	25	$\frac{59}{21}$	·44863	46	$\frac{75}{26}$	·46009	64	$\frac{71}{24}$	·47105	24
$\frac{52}{19}$	·43725	36	$\frac{45}{16}$	·44909	36	$\frac{26}{9}$	·46073	60	$\frac{74}{25}$	·47129	23
$\frac{63}{23}$	·43761	26	$\frac{76}{27}$	·44945	52	$\frac{81}{28}$	·46133	28	$\frac{77}{26}$	·47152	21
$\frac{74}{27}$	·43787	19	$\frac{31}{11}$	·44997	50	$\frac{55}{19}$	·46161	27	$\frac{80}{27}$	·47173	19
$\frac{85}{31}$	·43806	14	$\frac{79}{28}$	·45047	32	$\frac{84}{29}$	·46188	52	$\frac{83}{28}$	·47192	18
$\frac{96}{35}$	·43820	113	$\frac{48}{17}$	·45079	39	$\frac{29}{10}$	·46240	48	$\frac{86}{29}$	·47210	17
$\frac{11}{4}$	·43933	120	$\frac{65}{23}$	·45118	23	$\frac{90}{31}$	·46288	23	$\frac{89}{30}$	·47227	16
$\frac{91}{33}$	·44053	16	$\frac{82}{29}$	·45141	16	$\frac{61}{21}$	·46311	22	$\frac{92}{31}$	·47243	14
$\frac{80}{29}$	·44069	22	$\frac{99}{35}$	·45157	73	$\frac{93}{32}$	·46333	43	$\frac{95}{32}$	·47257	15
$\frac{69}{25}$	·44091	30	$\frac{17}{6}$	·45230	82	$\frac{32}{11}$	·46376	40	$\frac{98}{33}$	·47272	440
$\frac{58}{21}$	·44121	44	$\frac{88}{31}$	·45312	20	$\frac{99}{34}$	·46416	18	$\frac{3}{1}$	·47712	437
$\frac{47}{17}$	·44165	31	$\frac{71}{25}$	·45332	32	$\frac{67}{23}$	·46434	55	$\frac{100}{33}$	·48149	13
$\frac{83}{30}$	·44196	40	$\frac{54}{19}$	·45364	25	$\frac{35}{12}$	·46489	49	$\frac{97}{32}$	·48162	15
$\frac{36}{13}$	·44236	34	$\frac{91}{32}$	·45389	37	$\frac{73}{25}$	·46538	46	$\frac{94}{31}$	·48177	15
$\frac{97}{35}$	·44270	21	$\frac{37}{13}$	·45426	36	$\frac{38}{13}$	·46584	43	$\frac{91}{30}$	·48192	16
$\frac{61}{22}$	·44291	23	$\frac{94}{33}$	·45462	22	$\frac{79}{27}$	·46627	38	$\frac{88}{29}$	·48208	18
$\frac{86}{31}$	·44314	56	$\frac{57}{20}$	·45484	29	$\frac{41}{14}$	·46665	37	$\frac{85}{28}$	·48226	19
$\frac{25}{9}$	·44370	54	$\frac{77}{27}$	·45513	16	$\frac{85}{29}$	·46702	34	$\frac{82}{27}$	·48245	21
$\frac{89}{32}$	·44424	21	$\frac{97}{34}$	·45529	64	$\frac{44}{15}$	·46736	32	$\frac{79}{26}$	·48266	21
$\frac{64}{23}$	·44445	48	$\frac{20}{7}$	·45593	75	$\frac{91}{31}$	·46768	30	$\frac{76}{25}$	·48287	24
$\frac{39}{14}$	·44493	35	$\frac{83}{29}$	·45668	24	$\frac{47}{16}$	·46798	28	$\frac{73}{24}$	·48311	26
$\frac{92}{33}$	·44528	25	$\frac{63}{22}$	·45692	46	$\frac{97}{33}$	·46826	26	$\frac{70}{23}$	·48337	28
$\frac{53}{19}$	·44553	33	$\frac{43}{15}$	·45738	43	$\frac{50}{17}$	·46852	49	$\frac{67}{22}$	·48365	31
$\frac{67}{24}$	·44586	23	$\frac{66}{23}$	·45781	22	$\frac{53}{18}$	·46901	43	$\frac{64}{21}$	·48396	34
$\frac{81}{29}$	·44609	15	$\frac{89}{31}$	·45803	61	$\frac{56}{19}$	·46944	38	$\frac{61}{20}$	·48430	38
$\frac{95}{34}$	·44624	92	$\frac{23}{8}$	·45864	57	$\frac{59}{20}$	·46982	35	$\frac{58}{19}$	·48468	41
$\frac{14}{5}$	·44716	100	$\frac{95}{33}$	·45921	18	$\frac{62}{21}$	·47017	32	$\frac{55}{18}$	·48509	46
$\frac{87}{31}$	·44816	19	$\frac{72}{25}$	·45939	36	$\frac{65}{22}$	·47049	29	$\frac{52}{17}$	·48555	53
$\frac{73}{26}$	·44835	28	$\frac{49}{17}$	·45975	34	$\frac{68}{23}$	·47078	27	$\frac{49}{16}$	·48608	28

Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.
$\frac{95}{31}$	·48636	31	$\frac{63}{20}$	·49831	53	$\frac{81}{25}$	·51055	18	$\frac{67}{20}$	·52504	38
$\frac{46}{15}$	·48667	32	$\frac{41}{13}$	·49884	56	$\frac{94}{29}$	·51073	115	$\frac{57}{17}$	·52542	55
$\frac{89}{29}$	·48699	35	$\frac{60}{19}$	·49940	29	$\frac{13}{4}$	·51188	124	$\frac{47}{14}$	·52597	37
$\frac{43}{14}$	·48734	38	$\frac{79}{25}$	·49969	18	$\frac{88}{27}$	·51312	21	$\frac{84}{25}$	·52634	47
$\frac{83}{27}$	·48772	40	$\frac{98}{31}$	·49987	73	$\frac{75}{23}$	·51333	31	$\frac{37}{11}$	·52681	62
$\frac{40}{13}$	·48812	43	$\frac{19}{6}$	·50060	79	$\frac{62}{19}$	·51364	47	$\frac{64}{19}$	·52743	25
$\frac{77}{25}$	·48855	47	$\frac{92}{29}$	·50139	20	$\frac{49}{15}$	·51411	34	$\frac{91}{27}$	·52768	59
$\frac{37}{12}$	·48902	51	$\frac{73}{23}$	·50159	35	$\frac{85}{26}$	·51445	46	$\frac{27}{8}$	·52827	56
$\frac{71}{23}$	·48953	56	$\frac{54}{17}$	·50194	29	$\frac{36}{11}$	·51491	41	$\frac{98}{29}$	·52883	21
$\frac{34}{11}$	·49009	40	$\frac{89}{28}$	·50223	45	$\frac{95}{29}$	·51532	26	$\frac{71}{21}$	·52904	47
$\frac{99}{32}$	·49049	20	$\frac{35}{11}$	·50268	46	$\frac{59}{18}$	·51558	29	$\frac{44}{13}$	·52951	55
$\frac{65}{21}$	·49069	22	$\frac{86}{27}$	·50314	31	$\frac{82}{25}$	·51587	76	$\frac{61}{18}$	·53006	30
$\frac{96}{31}$	·49091	45	$\frac{51}{16}$	·50345	40	$\frac{23}{7}$	·51663	79	$\frac{78}{23}$	·53036	20
$\frac{31}{10}$	·49136	48	$\frac{67}{21}$	·50385	26	$\frac{79}{24}$	·51742	32	$\frac{95}{28}$	·53056	92
$\frac{90}{29}$	·49184	26	$\frac{83}{26}$	·50411	17	$\frac{56}{17}$	·51774	29	$\frac{17}{5}$	·53148	95
$\frac{59}{19}$	·49210	26	$\frac{99}{31}$	·50428	87	$\frac{89}{27}$	·51803	48	$\frac{92}{27}$	·53243	21
$\frac{87}{28}$	·49236	56	$\frac{16}{5}$	·50515	93	$\frac{33}{10}$	·51851	57	$\frac{75}{22}$	·53264	34
$\frac{28}{9}$	·49292	60	$\frac{93}{29}$	·50608	20	$\frac{76}{23}$	·51908	45	$\frac{58}{17}$	·53298	26
$\frac{81}{26}$	·49352	31	$\frac{77}{24}$	·50628	30	$\frac{43}{13}$	·51953	34	$\frac{99}{29}$	·53324	36
$\frac{53}{17}$	·49383	32	$\frac{61}{19}$	·50658	50	$\frac{96}{29}$	·51987	29	$\frac{41}{12}$	·53360	56
$\frac{78}{25}$	·49415	70	$\frac{45}{14}$	·50708	42	$\frac{53}{16}$	·52016	43	$\frac{65}{19}$	·53416	26
$\frac{25}{8}$	·49485	56	$\frac{74}{23}$	·50750	66	$\frac{63}{19}$	·52059	31	$\frac{89}{26}$	·53442	69
$\frac{97}{31}$	·49541	19	$\frac{29}{9}$	·50816	48	$\frac{73}{22}$	·52090	24	$\frac{24}{7}$	·53511	79
$\frac{72}{23}$	·49560	41	$\frac{100}{31}$	·50864	20	$\frac{83}{25}$	·52114	18	$\frac{79}{23}$	·53590	34
$\frac{47}{15}$	·49601	42	$\frac{71}{22}$	·50884	47	$\frac{93}{28}$	·52132	156	$\frac{55}{16}$	·53624	32
$\frac{69}{22}$	·49643	21	$\frac{42}{13}$	·50931	34	$\frac{10}{3}$	·52288	149	$\frac{86}{25}$	·53656	56
$\frac{91}{29}$	·49664	68	$\frac{97}{30}$	·50965	26	$\frac{97}{29}$	·52437	18	$\frac{31}{9}$	·53712	48
$\frac{22}{7}$	·49732	74	$\frac{55}{17}$	·50991	38	$\frac{87}{26}$	·52455	21	$\frac{100}{29}$	·53760	22
$\frac{85}{27}$	·49806	25	$\frac{68}{21}$	·51029	26	$\frac{77}{23}$	·52476	28	$\frac{69}{20}$	·53782	57

Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.
$\frac{38}{11}$	·53839	48	$\frac{93}{26}$	·55351	25	$\frac{100}{27}$	·56864	25	$\frac{23}{6}$	·58358	75
$\frac{83}{24}$	·53887	40	$\frac{68}{19}$	·55376	53	$\frac{63}{17}$	·56889	29	$\frac{96}{25}$	·58433	24
$\frac{45}{13}$	·53927	34	$\frac{43}{12}$	·55429	59	$\frac{89}{24}$	·56918	69	$\frac{73}{19}$	·58457	46
$\frac{97}{28}$	·53961	30	$\frac{61}{17}$	·55488	33	$\frac{26}{7}$	·56987	67	$\frac{50}{13}$	·58503	43
$\frac{52}{15}$	·53991	49	$\frac{79}{22}$	·55521	20	$\frac{93}{25}$	·57054	26	$\frac{77}{20}$	·58546	80
$\frac{59}{17}$	·54040	39	$\frac{97}{27}$	·55541	89	$\frac{67}{18}$	·57080	59	$\frac{27}{7}$	·58626	74
$\frac{66}{19}$	·54079	31	$\frac{18}{5}$	·55630	105	$\frac{41}{11}$	·57139	41	$\frac{85}{22}$	·58700	34
$\frac{73}{21}$	·54110	26	$\frac{83}{23}$	·55735	29	$\frac{97}{26}$	·57180	30	$\frac{58}{15}$	·58734	32
$\frac{80}{23}$	·54136	22	$\frac{65}{18}$	·55764	52	$\frac{56}{15}$	·57210	41	$\frac{89}{23}$	·58766	61
$\frac{87}{25}$	·54158	19	$\frac{47}{13}$	·55816	43	$\frac{71}{19}$	·57251	26	$\frac{31}{8}$	·58827	56
$\frac{94}{27}$	·54177	230	$\frac{76}{21}$	·55859	72	$\frac{86}{23}$	·57277	126	$\frac{97}{25}$	·58883	26
$\frac{7}{2}$	·54407	229	$\frac{29}{8}$	·55931	56	$\frac{15}{4}$	·57403	116	$\frac{66}{17}$	·58909	74
$\frac{95}{27}$	·54636	18	$\frac{98}{27}$	·55987	23	$\frac{94}{25}$	·57519	22	$\frac{35}{9}$	·58983	65
$\frac{88}{25}$	·54654	22	$\frac{69}{19}$	·56010	57	$\frac{79}{21}$	·57541	32	$\frac{74}{19}$	·59048	58
$\frac{81}{23}$	·54676	25	$\frac{40}{11}$	·56067	43	$\frac{64}{17}$	·57573	53	$\frac{39}{10}$	·59106	53
$\frac{74}{21}$	·54701	31	$\frac{91}{25}$	·56110	34	$\frac{49}{13}$	·57626	40	$\frac{82}{21}$	·59159	49
$\frac{67}{19}$	·54732	38	$\frac{51}{14}$	·56144	50	$\frac{83}{22}$	·57666	58	$\frac{43}{11}$	·59208	43
$\frac{60}{17}$	·54770	49	$\frac{62}{17}$	·56194	35	$\frac{34}{9}$	·57724	55	$\frac{90}{23}$	·59251	41
$\frac{53}{15}$	·54819	29	$\frac{73}{20}$	·56229	26	$\frac{87}{23}$	·57779	36	$\frac{47}{12}$	·59292	37
$\frac{99}{28}$	·54848	34	$\frac{84}{23}$	·56255	20	$\frac{53}{14}$	·57815	43	$\frac{98}{25}$	·59329	34
$\frac{46}{13}$	·54882	39	$\frac{95}{26}$	·56275	152	$\frac{72}{19}$	·57858	25	$\frac{51}{13}$	·59363	60
$\frac{85}{24}$	·54921	46	$\frac{11}{3}$	·56427	158	$\frac{91}{24}$	·57883	95	$\frac{55}{14}$	·59423	53
$\frac{39}{11}$	·54967	56	$\frac{92}{25}$	·56585	22	$\frac{19}{5}$	·57978	89	$\frac{59}{15}$	·59476	46
$\frac{71}{20}$	·55023	68	$\frac{81}{22}$	·56607	28	$\frac{99}{26}$	·58067	20	$\frac{63}{16}$	·59522	40
$\frac{32}{9}$	·55091	54	$\frac{70}{19}$	·56635	38	$\frac{80}{21}$	·58087	34	$\frac{67}{17}$	·59562	37
$\frac{89}{25}$	·55145	30	$\frac{59}{16}$	·56673	57	$\frac{61}{16}$	·58121	65	$\frac{71}{18}$	·59599	32
$\frac{57}{16}$	·55175	33	$\frac{48}{13}$	·56730	39	$\frac{42}{11}$	·58186	60	$\frac{75}{19}$	·59631	29
$\frac{82}{23}$	·55208	76	$\frac{85}{23}$	·56769	51	$\frac{65}{17}$	·58246	29	$\frac{79}{20}$	·59660	26
$\frac{25}{7}$	·55284	67	$\frac{37}{10}$	·56820	44	$\frac{88}{23}$	·58275	83	$\frac{83}{21}$	·59686	24

Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.
$\frac{87}{22}$	·59710	21	$\frac{29}{7}$	·61730	75	$\frac{56}{13}$	·63425	48	$\frac{94}{21}$	·65091	3 0
$\frac{91}{23}$	·59731	20	$\frac{83}{20}$	·61805	40	$\frac{69}{16}$	·63473	33	$\frac{9}{2}$	·65321	229
$\frac{95}{24}$	·59751	19	$\frac{54}{13}$	·61845	43	$\frac{82}{19}$	·63506	24	$\frac{95}{21}$	·65550	25
$\frac{99}{25}$	·59770	436	$\frac{79}{19}$	·61888	91	$\frac{95}{22}$	·63530	152	$\frac{86}{19}$	·65575	29
$\frac{4}{1}$	·60206	450	$\frac{25}{6}$	·61979	75	$\frac{13}{3}$	·63682	145	$\frac{77}{17}$	·65604	38
$\frac{97}{24}$	·60656	19	$\frac{96}{23}$	·62054	27	$\frac{100}{23}$	·63827	22	$\frac{68}{15}$	·65642	49
$\frac{93}{23}$	·60675	22	$\frac{71}{17}$	·62081	56	$\frac{87}{20}$	·63849	29	$\frac{59}{13}$	·65691	67
$\frac{89}{22}$	·60697	23	$\frac{46}{11}$	·62137	58	$\frac{74}{17}$	·63878	42	$\frac{50}{11}$	·65758	43
$\frac{85}{21}$	·60720	26	$\frac{67}{16}$	·62195	31	$\frac{61}{14}$	·63920	65	$\frac{91}{20}$	·65801	53
$\frac{81}{20}$	·60746	28	$\frac{88}{21}$	·62226	99	$\frac{48}{11}$	·63985	48	$\frac{41}{9}$	·65854	66
$\frac{77}{19}$	·60774	31	$\frac{21}{5}$	·62325	109	$\frac{83}{19}$	·64033	65	$\frac{73}{16}$	·65920	85
$\frac{73}{18}$	·60805	35	$\frac{80}{19}$	·62434	38	$\frac{35}{8}$	·64098	59	$\frac{32}{7}$	·66005	72
$\frac{69}{17}$	·60840	39	$\frac{59}{14}$	·62472	32	$\frac{92}{21}$	·64157	36	$\frac{87}{19}$	·66077	41
$\frac{65}{16}$	·60879	45	$\frac{97}{23}$	·62504	50	$\frac{57}{13}$	·64193	43	$\frac{55}{12}$	·66118	46
$\frac{61}{15}$	·60924	50	$\frac{38}{9}$	·62554	52	$\frac{79}{18}$	·64236	109	$\frac{78}{17}$	·66164	112
$\frac{57}{14}$	·60974	60	$\frac{93}{22}$	·62606	36	$\frac{22}{5}$	·64345	90	$\frac{23}{5}$	·66276	105
$\frac{53}{13}$	·61034	68	$\frac{55}{13}$	·62642	46	$\frac{97}{22}$	·64435	26	$\frac{83}{18}$	·66381	40
$\frac{49}{12}$	·61102	38	$\frac{72}{17}$	·62688	29	$\frac{75}{17}$	·64461	49	$\frac{60}{13}$	·66421	34
$\frac{94}{23}$	·61140	42	$\frac{89}{21}$	·62717	122	$\frac{53}{12}$	·64510	43	$\frac{97}{21}$	·66455	56
$\frac{45}{11}$	·61182	46	$\frac{17}{4}$	·62839	111	$\frac{84}{19}$	·64553	73	$\frac{37}{8}$	·66511	62
$\frac{86}{21}$	·61228	50	$\frac{98}{23}$	·62950	24	$\frac{31}{7}$	·64626	88	$\frac{88}{19}$	·66573	45
$\frac{41}{10}$	·61278	56	$\frac{81}{19}$	·62974	35	$\frac{71}{16}$	·64714	68	$\frac{51}{11}$	·66618	60
$\frac{78}{19}$	·61334	62	$\frac{64}{15}$	·63009	62	$\frac{40}{9}$	·64782	54	$\frac{65}{14}$	·66678	40
$\frac{37}{9}$	·61396	69	$\frac{47}{11}$	·63071	51	$\frac{89}{20}$	·64836	45	$\frac{79}{17}$	·66718	27
$\frac{70}{17}$	·61465	77	$\frac{77}{18}$	·63122	80	$\frac{49}{11}$	·64881	68	$\frac{93}{20}$	·66745	156
$\frac{33}{8}$	·61542	57	$\frac{30}{7}$	·63202	85	$\frac{58}{13}$	·64949	49	$\frac{14}{3}$	·66901	163
$\frac{95}{23}$	·61599	31	$\frac{73}{17}$	·63287	60	$\frac{67}{15}$	·64998	38	$\frac{89}{19}$	·67064	30
$\frac{62}{15}$	·61630	32	$\frac{43}{10}$	·63347	44	$\frac{76}{17}$	·65036	31	$\frac{75}{16}$	·67094	45
$\frac{91}{22}$	·61662	68	$\frac{99}{23}$	·63391	34	$\frac{85}{19}$	·65067	24	$\frac{61}{13}$	·67139	71

Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.
$\frac{47}{10}$	·67210	54	$\frac{54}{11}$	·69100	67	$\frac{88}{17}$	·71403	45	$\frac{38}{7}$	·73468	72
$\frac{80}{17}$	·67264	77	$\frac{59}{12}$	·69167	57	$\frac{57}{11}$	·71448	48	$\frac{87}{16}$	·73540	56
$\frac{33}{7}$	·67341	74	$\frac{64}{13}$	·69224	48	$\frac{83}{16}$	·71496	104	$\frac{49}{9}$	·73596	80
$\frac{85}{18}$	·67415	46	$\frac{69}{14}$	·69272	42	$\frac{26}{5}$	·71600	89	$\frac{60}{11}$	·73676	56
$\frac{52}{11}$	·67461	56	$\frac{74}{15}$	·69314	37	$\frac{99}{19}$	·71689	30	$\frac{71}{13}$	·73732	40
$\frac{71}{15}$	·67517	32	$\frac{79}{16}$	·69351	32	$\frac{73}{14}$	·71719	67	$\frac{82}{15}$	·73772	31
$\frac{90}{19}$	·67549	120	$\frac{84}{17}$	·69383	29	$\frac{47}{9}$	·71786	71	$\frac{93}{17}$	·73803	233
$\frac{19}{4}$	·67669	109	$\frac{89}{18}$	·69412	26	$\frac{68}{13}$	·71857	37	$\frac{11}{2}$	·74036	232
$\frac{100}{21}$	·67778	26	$\frac{84}{19}$	·69438	23	$\frac{89}{17}$	·71894	122	$\frac{94}{17}$	·74268	31
$\frac{81}{17}$	·67804	41	$\frac{99}{20}$	·69461	436	$\frac{21}{4}$	·72016	109	$\frac{83}{15}$	·74299	40
$\frac{62}{13}$	·67845	78	$\frac{5}{1}$	·69897	455	$\frac{100}{19}$	·72125	29	$\frac{72}{13}$	·74339	55
$\frac{43}{9}$	·67923	71	$\frac{96}{19}$	·70352	25	$\frac{79}{15}$	·72154	50	$\frac{61}{11}$	·74394	79
$\frac{67}{14}$	·67994	35	$\frac{91}{18}$	·70377	28	$\frac{58}{11}$	·72204	41	$\frac{50}{9}$	·74473	54
$\frac{91}{19}$	·68029	95	$\frac{86}{17}$	·70405	32	$\frac{95}{18}$	·72245	65	$\frac{89}{16}$	·74527	69
$\frac{24}{5}$	·68124	113	$\frac{81}{16}$	·70437	35	$\frac{37}{7}$	·72310	69	$\frac{39}{7}$	·74596	93
$\frac{77}{16}$	·68237	52	$\frac{76}{15}$	·70472	41	$\frac{90}{17}$	·72379	49	$\frac{67}{12}$	·74689	38
$\frac{53}{11}$	·68289	47	$\frac{71}{14}$	·70513	47	$\frac{53}{10}$	·72428	63	$\frac{95}{17}$	·74727	92
$\frac{82}{17}$	·68336	89	$\frac{66}{13}$	·70560	55	$\frac{69}{13}$	·72491	39	$\frac{28}{5}$	·74819	119
$\frac{29}{6}$	·68425	79	$\frac{61}{12}$	·70615	65	$\frac{85}{16}$	·72530	170	$\frac{73}{13}$	·74938	74
$\frac{92}{19}$	·68504	36	$\frac{56}{11}$	·70680	77	$\frac{16}{3}$	·72700	159	$\frac{45}{8}$	·75012	88
$\frac{63}{13}$	·68540	34	$\frac{51}{10}$	·70757	45	$\frac{91}{17}$	·72859	34	$\frac{62}{11}$	·75100	50
$\frac{97}{20}$	·68574	64	$\frac{97}{19}$	·70802	50	$\frac{75}{14}$	·72893	53	$\frac{79}{14}$	·75150	32
$\frac{34}{7}$	·68638	85	$\frac{46}{9}$	·70852	55	$\frac{59}{11}$	·72946	92	$\frac{96}{17}$	·75182	151
$\frac{73}{15}$	·68723	74	$\frac{87}{17}$	·70907	62	$\frac{43}{8}$	·73038	78	$\frac{17}{3}$	·75333	159
$\frac{39}{8}$	·68797	66	$\frac{41}{8}$	·70969	71	$\frac{70}{13}$	·73116	34	$\frac{91}{16}$	·75492	37
$\frac{83}{17}$	·68863	58	$\frac{77}{15}$	·71040	80	$\frac{97}{18}$	·73150	89	$\frac{74}{13}$	·75529	58
$\frac{44}{9}$	·68921	52	$\frac{36}{7}$	·71120	93	$\frac{27}{5}$	·73239	95	$\frac{57}{10}$	·75587	45
$\frac{93}{19}$	·68973	47	$\frac{67}{13}$	·71213	35	$\frac{92}{17}$	·73334	39	$\frac{97}{17}$	·75632	64
$\frac{49}{10}$	·69020	80	$\frac{98}{19}$	·71248	73	$\frac{65}{12}$	·73373	95	$\frac{40}{7}$	·75696	99
			$\frac{31}{6}$	·71321	82						

Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.
$\frac{63}{11}$	·75795	46	$\frac{79}{13}$	·78369	45	$\frac{45}{7}$	·80811	108	$\frac{89}{13}$	·83545	69
$\frac{86}{15}$	·75841	126	$\frac{73}{12}$	·78414	54	$\frac{58}{9}$	·80919	68	$\frac{48}{7}$	·83614	113
$\frac{23}{4}$	·75967	111	$\frac{67}{11}$	·78468	65	$\frac{71}{11}$	·80987	47	$\frac{55}{8}$	·83727	88
$\frac{98}{17}$	·76078	34	$\frac{61}{10}$	·78533	79	$\frac{84}{13}$	·81034	34	$\frac{62}{9}$	·83815	70
$\frac{75}{13}$	·76112	64	$\frac{55}{9}$	·78612	99	$\frac{97}{15}$	·81068	223	$\frac{69}{10}$	·83885	57
$\frac{52}{9}$	·76176	60	$\frac{49}{8}$	·78711	59	$\frac{13}{2}$	·81291	223	$\frac{76}{11}$	·83942	48
$\frac{81}{14}$	·76236	107	$\frac{92}{15}$	·78770	67	$\frac{98}{15}$	·81514	34	$\frac{83}{12}$	·83990	40
$\frac{29}{5}$	·76343	93	$\frac{43}{7}$	·78837	78	$\frac{85}{13}$	·81548	46	$\frac{90}{13}$	·84030	34
$\frac{93}{16}$	·76436	43	$\frac{80}{13}$	·78915	90	$\frac{72}{11}$	·81594	67	$\frac{97}{14}$	·84064	446
$\frac{64}{11}$	·76479	40	$\frac{37}{6}$	·79005	107	$\frac{59}{9}$	·81661	105	$\frac{7}{1}$	·84510	441
$\frac{99}{17}$	·76519	73	$\frac{68}{11}$	·79112	40	$\frac{46}{7}$	·81766	79	$\frac{99}{14}$	·84951	34
$\frac{35}{6}$	·76592	95	$\frac{99}{16}$	·79152	87	$\frac{79}{12}$	·81845	109	$\frac{92}{13}$	·84985	39
$\frac{76}{13}$	·76687	81	$\frac{31}{5}$	·79239	100	$\frac{33}{5}$	·81954	102	$\frac{85}{12}$	·85024	46
$\frac{41}{7}$	·76768	71	$\frac{87}{14}$	·79339	56	$\frac{86}{13}$	·82056	63	$\frac{78}{11}$	·85070	56
$\frac{88}{15}$	·76839	62	$\frac{56}{9}$	·79395	60	$\frac{53}{8}$	·82119	74	$\frac{71}{10}$	·85126	68
$\frac{47}{8}$	·76901	54	$\frac{81}{13}$	·79455	133	$\frac{73}{11}$	·82193	42	$\frac{64}{9}$	·85194	84
$\frac{100}{17}$	·76955	49	$\frac{25}{4}$	·79588	116	$\frac{93}{14}$	·82235	156	$\frac{57}{8}$	·85278	109
$\frac{53}{9}$	·77004	81	$\frac{94}{15}$	·79704	42	$\frac{20}{3}$	·82391	167	$\frac{50}{7}$	·85387	67
$\frac{59}{10}$	·77085	67	$\frac{69}{11}$	·79746	89	$\frac{87}{13}$	·82558	49	$\frac{93}{13}$	·85454	78
$\frac{65}{11}$	·77152	56	$\frac{44}{7}$	·79835	99	$\frac{67}{10}$	·82607	93	$\frac{43}{6}$	·85532	92
$\frac{71}{12}$	·77208	47	$\frac{63}{10}$	·79934	53	$\frac{47}{7}$	·82700	84	$\frac{79}{11}$	·85624	109
$\frac{77}{13}$	·77255	40	$\frac{82}{13}$	·79987	176	$\frac{74}{11}$	·82784	146	$\frac{36}{5}$	·85733	134
$\frac{83}{14}$	·77295	35	$\frac{19}{3}$	·80163	163	$\frac{27}{4}$	·82930	124	$\frac{65}{9}$	·85867	52
$\frac{89}{15}$	·77330	30	$\frac{89}{14}$	·80326	45	$\frac{88}{13}$	·83054	55	$\frac{94}{13}$	·85919	115
$\frac{95}{16}$	·77360	455	$\frac{70}{11}$	·80371	77	$\frac{61}{9}$	·83109	50	$\frac{29}{4}$	·86034	136
$\frac{6}{1}$	·77815	450	$\frac{51}{8}$	·80448	66	$\frac{95}{14}$	·83159	92	$\frac{80}{11}$	·86170	77
$\frac{97}{16}$	·78265	30	$\frac{83}{13}$	·80514	104	$\frac{34}{5}$	·83251	116	$\frac{61}{7}$	·86247	85
$\frac{91}{15}$	·78295	34	$\frac{32}{5}$	·80618	113	$\frac{75}{11}$	·83367	96	$\frac{73}{10}$	·86332	46
$\frac{85}{14}$	·78329	40	$\frac{77}{12}$	·80731	80	$\frac{41}{6}$	·83463	82	$\frac{95}{13}$	·86378	152

Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.
$\frac{22}{3}$	·86530	180	$\frac{47}{6}$	·89395	131	$\frac{17}{2}$	·92942	232	$\frac{83}{9}$	·96484	130
$\frac{81}{11}$	·86710	66	$\frac{55}{7}$	·89526	99	$\frac{94}{11}$	·93174	51	$\frac{37}{4}$	·96614	167
$\frac{59}{8}$	·86776	57	$\frac{63}{8}$	·89625	77	$\frac{77}{9}$	·93225	80	$\frac{65}{7}$	·96781	67
$\frac{96}{13}$	·86833	90	$\frac{71}{9}$	·89702	61	$\frac{60}{7}$	·93305	145	$\frac{93}{10}$	·96848	156
$\frac{37}{5}$	·86923	98	$\frac{79}{10}$	·89763	50	$\frac{43}{5}$	·93450	126	$\frac{28}{3}$	·97004	193
$\frac{89}{12}$	·87021	69	$\frac{87}{11}$	·89813	41	$\frac{69}{8}$	·93576	57	$\frac{75}{8}$	·97197	116
$\frac{52}{7}$	·87090	93	$\frac{95}{12}$	·89854	455	$\frac{95}{11}$	·93633	152	$\frac{47}{5}$	·97313	131
$\frac{67}{9}$	·87183	59	$\frac{8}{1}$	·90309	450	$\frac{26}{3}$	·93785	167	$\frac{66}{7}$	·97444	74
$\frac{82}{11}$	·87242	41	$\frac{97}{12}$	·90759	41	$\frac{87}{10}$	·93952	71	$\frac{85}{9}$	·97518	254
$\frac{97}{13}$	·87283	223	$\frac{89}{11}$	·90800	49	$\frac{61}{7}$	·94023	65	$\frac{19}{2}$	·97772	254
$\frac{15}{2}$	·87506	223	$\frac{81}{10}$	·90849	59	$\frac{96}{11}$	·94088	113	$\frac{86}{9}$	·98026	71
$\frac{98}{13}$	·87729	40	$\frac{73}{9}$	·90908	74	$\frac{35}{4}$	·94201	138	$\frac{67}{7}$	·98097	130
$\frac{83}{11}$	·87769	58	$\frac{65}{8}$	·90982	95	$\frac{79}{9}$	·91339	109	$\frac{48}{5}$	·98227	113
$\frac{68}{9}$	·87827	91	$\frac{57}{7}$	·91077	128	$\frac{44}{5}$	·94448	90	$\frac{77}{8}$	·98340	188
$\frac{53}{7}$	·87918	68	$\frac{49}{6}$	·91205	80	$\frac{97}{11}$	·94538	75	$\frac{29}{3}$	·98528	149
$\frac{91}{12}$	·87986	95	$\frac{90}{11}$	·91285	96	$\frac{53}{6}$	·94613	116	$\frac{97}{10}$	·98677	64
$\frac{38}{5}$	·88081	89	$\frac{41}{5}$	·91381	118	$\frac{62}{7}$	·94729	88	$\frac{68}{7}$	·98741	159
$\frac{99}{13}$	·88170	54	$\frac{74}{9}$	·91499	146	$\frac{71}{8}$	·94817	68	$\frac{39}{4}$	·98900	124
$\frac{61}{8}$	·88224	65	$\frac{33}{4}$	·91645	120	$\frac{80}{9}$	·94885	54	$\frac{88}{9}$	·99024	99
$\frac{84}{11}$	·88289	172	$\frac{91}{11}$	·91765	68	$\frac{89}{10}$	·94939	45	$\frac{49}{5}$	·99123	147
$\frac{23}{3}$	·88461	145	$\frac{58}{7}$	·91833	75	$\frac{98}{11}$	·94984	440	$\frac{59}{6}$	·99270	105
$\frac{100}{13}$	·88606	43	$\frac{83}{10}$	·91908	174	$\frac{9}{1}$	·95424	437	$\frac{69}{7}$	·99375	79
$\frac{77}{10}$	·88649	80	$\frac{25}{3}$	·92082	158	$\frac{100}{11}$	·95861	43	$\frac{79}{8}$	·99454	61
$\frac{54}{7}$	·88729	74	$\frac{92}{11}$	·92240	58	$\frac{91}{10}$	·95904	53	$\frac{89}{9}$	·99515	49
$\frac{85}{11}$	·88803	127	$\frac{67}{8}$	·92298	130	$\frac{82}{9}$	·95957	66	$\frac{99}{10}$	·99564	436
$\frac{31}{4}$	·88930	156	$\frac{42}{5}$	·92428	147	$\frac{73}{8}$	·96023	85	$\frac{10}{1}$	1·00000	480
$\frac{70}{9}$	·89086	123	$\frac{59}{7}$	·92575	82	$\frac{64}{7}$	·96108	113	$\frac{91}{9}$	1·00480	60
$\frac{39}{5}$	·89209	102	$\frac{76}{9}$	·92657	52	$\frac{55}{6}$	·96221	158	$\frac{81}{8}$	1·00540	76
$\frac{86}{11}$	·89311	84	$\frac{93}{11}$	·92709	233	$\frac{46}{5}$	·96379	105	$\frac{71}{7}$	1·00616	102

Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.
$\frac{61}{6}$	1·00718	142	$\frac{56}{5}$	1·04922	193	$\frac{25}{2}$	1·09691	247	$\frac{85}{6}$	1·15127	102
$\frac{51}{5}$	1·00860	95	$\frac{45}{4}$	1·05115	138	$\frac{88}{7}$	1·09938	99	$\frac{71}{5}$	1·15229	152
$\frac{92}{9}$	1·00955	117	$\frac{79}{7}$	1·05253	183	$\frac{63}{5}$	1·10037	229	$\frac{57}{4}$	1·15381	109
$\frac{41}{4}$	1·01072	151	$\frac{34}{3}$	1·05436	159	$\frac{38}{3}$	1·10266	163	$\frac{100}{7}$	1·15490	145
$\frac{72}{7}$	1·01223	201	$\frac{91}{8}$	1·05595	95	$\frac{89}{7}$	1·10429	122	$\frac{43}{3}$	1·15635	201
$\frac{31}{3}$	1·01424	175	$\frac{57}{5}$	1·05690	109	$\frac{51}{4}$	1·10551	170	$\frac{72}{5}$	1·15836	301
$\frac{83}{8}$	1·01599	104	$\frac{80}{7}$	1·05799	271	$\frac{64}{5}$	1·10721	113	$\frac{29}{2}$	1·16137	298
$\frac{52}{5}$	1·01703	119	$\frac{23}{2}$	1·06070	269	$\frac{77}{6}$	1·10834	80	$\frac{73}{5}$	1·16435	198
$\frac{73}{7}$	1·01822	67	$\frac{81}{7}$	1·06339	107	$\frac{90}{7}$	1·10914	480	$\frac{44}{3}$	1·16633	246
$\frac{94}{9}$	1·01889	230	$\frac{58}{5}$	1·06446	93	$\frac{13}{1}$	1·11394	475	$\frac{59}{4}$	1·16879	147
$\frac{21}{2}$	1·02119	229	$\frac{93}{8}$	1·06539	156	$\frac{92}{7}$	1·11869	79	$\frac{74}{5}$	1·17026	98
$\frac{95}{9}$	1·02348	65	$\frac{35}{3}$	1·06695	176	$\frac{79}{6}$	1·11948	109	$\frac{89}{6}$	1·17124	485
$\frac{74}{7}$	1·02413	118	$\frac{82}{7}$	1·06871	133	$\frac{66}{5}$	1·12057	165	$\frac{15}{1}$	1·17609	480
$\frac{53}{5}$	1·02531	102	$\frac{47}{4}$	1·07004	184	$\frac{53}{4}$	1·12222	116	$\frac{91}{6}$	1·18089	95
$\frac{85}{8}$	1·02633	170	$\frac{59}{5}$	1·07188	123	$\frac{93}{7}$	1·12338	156	$\frac{76}{5}$	1·18184	143
$\frac{32}{3}$	1·02803	193	$\frac{71}{6}$	1·07311	87	$\frac{40}{3}$	1·12494	216	$\frac{61}{4}$	1·18327	237
$\frac{75}{7}$	1·02996	145	$\frac{83}{7}$	1·07398	65	$\frac{67}{5}$	1·12710	93	$\frac{46}{3}$	1·18564	188
$\frac{43}{4}$	1·03141	112	$\frac{95}{8}$	1·07463	455	$\frac{94}{7}$	1·12803	230	$\frac{77}{5}$	1·18752	281
$\frac{97}{9}$	1·03253	89	$\frac{12}{1}$	1·07918	450	$\frac{27}{2}$	1·13033	229	$\frac{31}{2}$	1·19033	279
$\frac{54}{5}$	1·03342	134	$\frac{97}{8}$	1·08368	64	$\frac{95}{7}$	1·13262	92	$\frac{78}{5}$	1·19312	186
$\frac{65}{6}$	1·03476	95	$\frac{85}{7}$	1·08432	85	$\frac{68}{5}$	1·13354	212	$\frac{47}{3}$	1·19498	230
$\frac{76}{7}$	1·03571	72	$\frac{73}{6}$	1·08517	119	$\frac{41}{3}$	1·13566	151	$\frac{63}{4}$	1·19728	138
$\frac{87}{8}$	1·03643	56	$\frac{61}{5}$	1·08636	178	$\frac{96}{7}$	1·13717	113	$\frac{79}{5}$	1·19866	91
$\frac{98}{9}$	1·03699	440	$\frac{49}{4}$	1·08814	126	$\frac{55}{4}$	1·13830	158	$\frac{95}{6}$	1·19957	455
$\frac{11}{1}$	1·04139	437	$\frac{86}{7}$	1·08940	168	$\frac{69}{5}$	1·13988	105	$\frac{16}{1}$	1·20412	450
$\frac{100}{9}$	1·04576	54	$\frac{37}{3}$	1·09108	147	$\frac{83}{6}$	1·14093	74	$\frac{97}{6}$	1·20862	90
$\frac{89}{8}$	1·04630	69	$\frac{99}{8}$	1·09255	87	$\frac{97}{7}$	1·14167	446	$\frac{81}{5}$	1·20952	133
$\frac{78}{7}$	1·04699	93	$\frac{62}{5}$	1·09342	100	$\frac{14}{1}$	1·14613	441	$\frac{65}{4}$	1·21085	223
$\frac{67}{6}$	1·04792	130	$\frac{87}{7}$	1·09442	249	$\frac{99}{7}$	1·15054	73	$\frac{49}{3}$	1·21308	176

Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.
$\frac{82}{5}$	1·21484	264	$\frac{58}{3}$	1·28631	149	$\frac{71}{3}$	1·37414	152	$\frac{91}{3}$	1·48192	238
$\frac{33}{2}$	1·21748	263	$\frac{97}{5}$	1·28780	223	$\frac{95}{4}$	1·37566	455	$\frac{61}{2}$	1·48430	237
$\frac{83}{5}$	1·22011	174	$\frac{39}{2}$	1·29003	223	$\frac{24}{1}$	1·38021	450	$\frac{92}{3}$	1·48667	469
$\frac{50}{3}$	1·22185	216	$\frac{98}{5}$	1·29226	147	$\frac{97}{4}$	1·38471	149	$\frac{31}{1}$	1·49136	465
$\frac{67}{4}$	1·22401	130	$\frac{59}{3}$	1·29373	184	$\frac{73}{3}$	1·38620	297	$\frac{94}{3}$	1·49601	230
$\frac{84}{5}$	1·22531	514	$\frac{79}{4}$	1·29557	110	$\frac{49}{2}$	1·38917	294	$\frac{63}{2}$	1·49831	229
$\frac{17}{1}$	1·23045	508	$\frac{99}{5}$	1·29667	436	$\frac{74}{3}$	1·39211	147	$\frac{95}{3}$	1·50060	455
$\frac{86}{5}$	1·23553	126	$\frac{20}{1}$	1·30103	540	$\frac{99}{4}$	1·39358	436	$\frac{32}{1}$	1·50515	450
$\frac{69}{4}$	1·23679	209	$\frac{81}{4}$	1·30643	178	$\frac{25}{1}$	1·39794	575	$\frac{97}{3}$	1·50965	223
$\frac{52}{3}$	1·23888	167	$\frac{61}{3}$	1·30821	354	$\frac{76}{3}$	1·40369	285	$\frac{65}{2}$	1·51188	223
$\frac{87}{5}$	1·24055	249	$\frac{41}{2}$	1·31175	352	$\frac{51}{2}$	1·40654	283	$\frac{98}{3}$	1·51411	440
$\frac{35}{2}$	1·24304	247	$\frac{62}{3}$	1·31527	175	$\frac{77}{3}$	1·40937	560	$\frac{33}{1}$	1·51851	437
$\frac{88}{5}$	1·24551	165	$\frac{83}{4}$	1·31702	520	$\frac{26}{1}$	1·41497	554	$\frac{100}{3}$	1·52288	216
$\frac{53}{3}$	1·24716	204	$\frac{21}{1}$	1·32222	514	$\frac{79}{3}$	1·42051	274	$\frac{67}{2}$	1·52504	644
$\frac{71}{4}$	1·24920	122	$\frac{85}{4}$	1·32736	170	$\frac{53}{2}$	1·42325	272	$\frac{34}{1}$	1·53148	634
$\frac{89}{5}$	1·25042	485	$\frac{64}{3}$	1·32906	338	$\frac{80}{3}$	1·42597	539	$\frac{69}{2}$	1·53782	625
$\frac{18}{1}$	1·25527	480	$\frac{43}{2}$	1·33244	335	$\frac{27}{1}$	1·43136	533	$\frac{35}{1}$	1·54407	616
$\frac{91}{5}$	1·26007	119	$\frac{65}{3}$	1·33579	167	$\frac{82}{3}$	1·43669	264	$\frac{71}{2}$	1·55023	607
$\frac{73}{4}$	1·26126	198	$\frac{87}{4}$	1·33746	496	$\frac{55}{2}$	1·43933	263	$\frac{36}{1}$	1·55630	599
$\frac{55}{3}$	1·26324	158	$\frac{22}{1}$	1·34242	491	$\frac{83}{3}$	1·44196	520	$\frac{73}{2}$	1·56229	591
$\frac{92}{5}$	1·26482	235	$\frac{89}{4}$	1·34733	162	$\frac{28}{1}$	1·44716	514	$\frac{37}{1}$	1·56820	583
$\frac{37}{2}$	1·26717	234	$\frac{67}{3}$	1·34895	323	$\frac{85}{3}$	1·45230	254	$\frac{75}{2}$	1·57403	575
$\frac{93}{5}$	1·26951	156	$\frac{45}{2}$	1·35218	321	$\frac{57}{2}$	1·45484	254	$\frac{38}{1}$	1·57978	568
$\frac{56}{3}$	1·27107	193	$\frac{68}{3}$	1·35539	159	$\frac{86}{3}$	1·45738	502	$\frac{77}{2}$	1·58546	560
$\frac{75}{4}$	1·27300	116	$\frac{91}{4}$	1·35698	475	$\frac{29}{1}$	1·46240	496	$\frac{39}{1}$	1·59106	554
$\frac{94}{5}$	1·27416	459	$\frac{23}{1}$	1·36173	469	$\frac{88}{3}$	1·46736	246	$\frac{79}{2}$	1·59660	546
$\frac{19}{1}$	1·27875	455	$\frac{93}{4}$	1·36642	156	$\frac{59}{2}$	1·46982	245	$\frac{40}{1}$	1·60206	540
$\frac{96}{5}$	1·28330	113	$\frac{70}{3}$	1·36798	309	$\frac{89}{3}$	1·47227	485	$\frac{81}{2}$	1·60746	532
$\frac{77}{4}$	1·28443	188	$\frac{47}{2}$	1·37107	307	$\frac{30}{1}$	1·47712	480	$\frac{41}{1}$	1·61278	527

Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.	Vulgar Fraction.	Logarithm.	Difference.
83/2	1·61805	520	50/1	1·69897	860	67/1	1·82607	644	84/1	1·92428	514
42/1	1·62325	514	51/1	1·70757	843	68/1	1·83251	634	85/1	1·92942	508
85/2	1·62839	508	52/1	1·71600	828	69/1	1·83885	625	86/1	1·93450	502
43/1	1·63347	502	53/1	1·72428	811	70/1	1·84510	616	87/1	1·93952	496
87/2	1·63849	496	54/1	1·73239	797	71/1	1·85126	607	88/1	1·94448	491
44/1	1·64345	491	55/1	1·74036	783	72/1	1·85733	599	89/1	1·94939	485
89/2	1·64836	485	56/1	1·74819	768	73/1	1·86332	591	90/1	1·95424	480
45/1	1·65321	480	57/1	1·75587	756	74/1	1·86923	583	91/1	1·95904	475
91/2	1·65801	475	58/1	1·76343	742	75/1	1·87506	575	92/1	1·96379	469
46/1	1·66276	469	59/1	1·77085	730	76/1	1·88081	568	93/1	1·96848	465
93/2	1·66745	465	60/1	1·77815	718	77/1	1·88649	560	94/1	1·97313	459
47/1	1·67210	459	61/1	1·78533	706	78/1	1·89209	554	95/1	1·97772	455
95/2	1·67669	455	62/1	1·79239	695	79/1	1·89763	546	96/1	1·98227	450
48/1	1·68124	450	63/1	1·79934	684	80/1	1·90309	540	97/1	1·98677	446
97/2	1·68574	446	64/1	1·80618	673	81/1	1·90849	532	98/1	1·99123	441
49/1	1·69020	441	65/1	1·81291	663	82/1	1·91381	527	99/1	1·99564	436
99/2	1·69461	436	66/1	1·81954	653	83/1	1·91908	520	100/1	2·00000	

The application of this Table may be understood from examples like the following:—

Example 1. Two spindles of wheel-work are to rotate in the proportion of angular speed 1 : 1·6199; it is required to find the numbers of teeth in the gearing wheels which will produce this relative angular speed.

The logarithm of 1·6199 is 0·20948. On referring to the Table, the following fractions and their logarithms will be found:—

$$\text{Log.}\ \frac{34}{21} = 0\cdot20926,$$

$$\text{Log.}\ \frac{81}{50} = 0\cdot20952.$$

Either of these fractions (containing the numbers of the teeth in the gearing wheels) gives a proportion very near to that which is required. The combination $\frac{34}{21}$ has the smaller number of teeth; the combination $\frac{81}{50}$ gives a result nearer to that which is required. If greater accuracy is desired, the process of the next Example must be used:—

Example 2. The relative angular speed is to be 1 : 1·9879. The logarithm of 1·9879 is 0·29839. The Table gives the following as the nearest logarithms:—

$$\text{Log.}\ \frac{97}{49} = 0\cdot29657.$$

$$\text{Log.}\ \frac{2}{1} = 0\cdot30103.$$

Neither of these logarithms, or the proportions of angular speed which they represent, is sufficiently near to that desired to be available for very accurate purposes. There must be introduced an intermediate spindle, which is represented numerically by finding two logarithms in the Table whose sum nearly equals 0·29839. This problem is truly indefinite; probably some combinations may be found which produce coincidence to the last figure; many scores of combinations will give numbers in error only to 0·00001 or 0·00002. Thus:

$$\left.\begin{array}{l}\text{Log.}\ \frac{85}{83} = 0\cdot01034\\ \text{Log.}\ \frac{33}{17} = 0\cdot28806\end{array}\right\}\text{Sum, log.}\left(\frac{85}{83}\times\frac{33}{17}\right) = 0\cdot29840.$$

The extent of the Table will be found sufficient in all cases to give a result accurate to ·00001 of logarithm.

(*Paper No. 1792.*)

"Three Systems of Wire-Rope Transport."

By William Thomas Henney Carrington, Assoc. M. Inst. C.E.

The Author proposes to describe three systems of wire-rope transport, each of which he has successfully applied on many occasions. The examples, hereafter referred to in detail, are those which in his opinion will give the best idea of the applicability and capabilities of each system. They are:—

(1) An example of the single running rope system, invented by Mr. Charles Hodgson, with improvements by the Author.
(2) An example of the double fixed rope system, worked on the gravitation plan.
(3) An example of the single fixed rope system.

A fourth system, of two fixed ropes, has been described in the Minutes of Proceedings, by Mr. Churchward, Assoc. M. Inst. C.E., in a Paper on the Monte Penna Wire Ropeway, lately erected by him from the Author's designs.[1]

It is believed the following details will show, that the several systems of wire-rope transport will form a useful and economical means of moving materials in situations where a railway or a road would be too costly or impracticable.

Running Rope System.

The example of the single running rope system selected for description is that of a line erected in the Cape de Verd Islands, at Messrs. Cory Brothers and Company's Coal Depôt, shown on Plate 4, Figs. 1, 2, and 3. Its total length is 500 yards, of which length about 320 yards extend along the beach, and about 80 yards at right angles to the longer section to the end of a pier, where the coal is received and despatched. The ropeway was required to be able to carry 15 tons of coal per hour in either direction, and the motion of the rope was to be utilized in working cranes at each terminal for raising or lowering coal. The coal is brought to the pier in bulk in barges from the colliers, and the buckets of the wire ropeway are lowered into the barges by a crane, and when filled are again raised, and sent off on the ropeway to the depôt at its further end, where a quantity of about 10,000 tons is usually stored. To supply the steamers calling at the island, the coal is filled at the store into bags holding 2 cwt., raised by a crane to the level of the wire ropeway, and carried by it back to the barges at the end of the pier.

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[1] *Vide* Minutes of Proceedings, Inst. C.E., vol. lxiii., p. 273.

The driving gear with its steam engine is placed at the point where the two sections of the wire ropeway meet at right angles. It consists of a massive wooden frame, carrying an upright shaft fitted at its upper end with two drums 8 feet in diameter, lying one on the top of the other, the ropes of the sections passing round these two drums, and being driven by them. At the lower end of the vertical shaft bevel gear is fixed, by which the motion of the steam engine is communicated to the drums. The usual shunt rails allow the loads to pass round the angle thus formed.

The steam engine is of 16 HP. nominal, has two cylinders, and is fitted with a surface condenser, it being impossible to obtain any fresh water for the boiler in the island except by distillation. The boiler is of the ordinary horizontal multitubular type, cylindrical throughout; it is worked up to a pressure of 60 lbs. The terminal at the end of the shorter section on the pier-head carries the horizontal drum round which the tramway rope passes, and a long horseshoe-shaped rail. On this frame is also mounted a crane, having a radius of 17 feet, and worked by shafting from the engine. This crane is manipulated by a friction clutch, actuated by a lever on the top of the frame, on which the man stands and has a clear view of the work going on below. Four buckets, each holding 2½ cwt., are lifted at a speed of 80 feet per minute, and deposited on to a deck alongside the terminal frame. The buckets are then pushed, singly, down an inclined plane, so arranged that they engage themselves on the hangers which, with their saddles, carry them on the line-rope. In a similar way the empty buckets arriving, or the sacks for delivery, are detached and lowered into the barge. The terminal at the end of the longer section at the coal store is placed on a wooden platform, about 20 feet above the ground, and 120 feet long. At the end of this, farthest from the driving station, is fixed a horizontal drum 8 feet in diameter, carried on a strong wooden frame, round which the line-rope passes, and which can be drawn back when required to take up any extension. The motion of the rope actuates the drum, which, by a pair of bevel wheels, turns a square shaft, extending along the centre of the platform for its whole length. A crane, of similar construction to that on the pier-head, is placed on the platform in front of the terminal, and can be moved from end to end, deriving motion from the line-rope through the square shaft at any point. The jib of this crane is long enough to enable loads to be hoisted on either side of the platform, and to be put down just behind the travelling shunt frame, which stands about 15 feet in front of the crane, and which is arranged to slide up and down the full length of the platform in conjunction with it. Thus the sacks of coal, having been raised from the ground, are placed at the foot of the shunt stage, by which they are, having been hung on the hangers, pushed on to the moving rope, and transported to the pier. When coal is being brought to the store, it is tipped into an inclined shoot out of the buckets while they hang on the rail of the moving shunt. It will be seen from the arrangements described, that the coal can be hoisted out of the barge at the pier-head, transported to the terminal depôt, and delivered into store, where it is duly put into sacks for re-delivery to steamers; and when this is required the sacks of coal can be lifted up to the ropeway, a height of 20 feet, transported to the pier-head, and deposited into the barges.

The rope is supported on the longer section by seven posts, which are fixed in the beach, and are of the usual construction, about 15 feet high; these posts carry bearing pulleys 2 feet in diameter, grooved to fit the wire rope, which is of crucible steel of a breaking strain of 16 tons. The rope is run at a speed of 3½ miles per hour. This ropeway has carried about 130,000 tons. Though it was only designed to lift and carry 15 tons per hour, it has on emergencies conveyed more than 25 tons in an hour.

The cost of maintenance of the rope has been about ½*d.* per ton, that of the machinery about ½*d.*, chiefly owing to the breaking of the buckets by rough use when hoisting. Thus the cost of maintenance may be taken at 1*d.* per ton, not allowing for the special duty levied on the renewals on entering the island. The cost of labour employed in working this ropeway has been greater than usual, as natives are employed. It amounts to 1*d.* per ton, including tipping the coal into store, and attending the engine. The cost of working the crane and filling the buckets in the barge has been about ⅝*d.* per ton. The engine burns 7 cwt. of coal every twelve hours. The operations are generally superintended by an English foreman, who also looks after the other mechanical work on the establishment.

The cost of these works complete erected on the spot, but exclusive of freight and customs duty, was about £2,500, which also included the large staging at the depôt, and the woodwork throughout. The whole of the materials were fitted together in England, marked, and taken to pieces again. The erection on the site occupied about three months, and was carried out by Mr. W. P. Churchward, Assoc. M. Inst. C.E., from the designs and under the general supervision of the Author.

DOUBLE FIXED ROPE SYSTEM.

The first example of the system of transport on fixed wire ropes is that of a series of self-acting inclines, of a total length of 2,844 yards, forming a means of conveyance for the lead-ore from the mines of the Sentein Mining Company, in the Pyrenees, near St. Girons, France. These mines, which are of great extent and unusual richness, are situated at a height of about 7,000 feet above the sea, near the summit of a mule pass over the Pyrenees. Though they have been worked for many years, their elevated position has prevented them from becoming a financial success, the distance to the dressing floors being 2 miles in a direct line, and the fall about 3,000 feet. Immense expense was incurred by the former proprietors in constructing a cart-road up to the mines, which, though extremely steep at many points, and very narrow, required to be about 10 miles long to connect the mines with the dressing floors.

On the property coming into the hands of the Sentein Mining Company, the question of transport presented itself as vitally important to the profitable working of the mine. With the road it was possible to bring down by carts about 30 tons per day of lead-ore, at a cost of about 8*s.* per ton, but this was only practicable in good weather, and in winter was impassable owing to the road snow. The Directors of the Sentein Company applied to the Author to advise them on the question of applying wire-rope transport for the greater part of the distance. He found it possible to recommend the application of a series of self-acting wire-rope inclines (common on a small scale in the district) by which the ore could be brought down to a point about ¾ mile from the works, from whence there was a good cart-road. This suggestion was adopted, and wire ropeways were erected from the designs of the Author (Plate 4, Figs. 4, 5, 6 and 7).

The inclines are five in number; the lower terminals of one join the upper terminals of the next, a suitable spot for these junctions being found at the ends or sides of the spurs of the mountain near the line of the wire ropeway.

The lengths and inclinations of the sections are as follow :—

No. 1	271 yards long	33 yards fall.
No. 2	675 „ „	230 „ „
No. 3	410 „ „	90 „ „
No. 4	978 „ „	430 „ „
No. 5	510 „ „	130 „ „
Totals . .	2,844	913

No. 1 incline commences at the mouth of the mine, and forms a junction with No. 2 incline at the edge of a cliff about 300 feet high. No. 2 incline crosses a span of 675 yards, and joins No. 3 incline on an elevated point on the steep side of the mountain, a small platform being cut out of its side for that purpose. No. 3 incline, stretching across a deep ravine, effects a junction with No. 4 incline at the extreme end of a spur of the mountain, a flat space being cut off its pointed top, the sides shelving at an angle of 60° with the horizon. No. 4 incline, spanning a valley 978 yards across, and about 1,500 feet deep, joins No. 5 incline on the side of the mountain. No. 5 incline stretches thence down into the bottom of the valley, terminating close to the cart-road to the works.

These inclines are identical in principle, differing only in length and inclination. They consist of two crucible-steel fixed ropes, of 75 tons breaking strain, anchored at the upper end, and stretched across the space between the terminals, the lower end being held by a pair of blocks fitted with Bullivant's flexible steel-wire rope, by which the fixed ropes are tightened. At each end they pass over a massive masonry saddle. The blocks by which they are tightened are fitted with a long flexible rope, to allow of their being slackened out enough to lie on the ground for the purpose of repairs ; the strain put on them is about 12 tons. The carriers for the ore are made of steel plates, measure about 2 feet 9 inches long by 2 feet wide and 2 feet deep, and are hung on the fixed ropes by a curved hanger, fitting into a pair of plates carrying between them two deeply-grooved steel wheels 15 inches in diameter on the tread, which fits the fixed rope. These plates also carry a small wheel under the fixed rope, which is placed so as not to touch it, but to prevent the larger grooved wheels being jerked off.

The carriers empty by the bottoms falling on the turning of a handle fixed to their sides. They are intended to carry from 14 to 15 cwt. each. One of these is placed on each of the two parallel fixed ropes, and the two are connected by a light wire rope of 7 tons breaking strain, of such a length that when one carrier is at the upper end of one fixed rope the other is at the lower end of the second parallel rope. Thus, when one carrier is charged with 14 cwt. of ore while standing on the upper end of the fixed rope, it runs down this rope, dragging up the empty carrier on the second fixed rope by means of the light hauling rope, the speed being governed by a powerful brake. This hauling rope passes round a break gear at the end of the incline. It consists of two vertical wheels, 5 feet in diameter, having grooved wooden rims, placed 5 feet apart, each wheel being fitted with a powerful brake.

The hauling rope passes over the first of these, next round a wheel 5 feet in diameter, placed horizontally in front at the feet of the two vertical wheels, and then round the second vertical wheel; by this means the adhesion on the two vertical brake-wheels is equal to rather more than that derived from two half turns on these wheels. A second hauling rope of the same size connects the carriers by passing round a horizontal drum at the lower end of the incline, which is arranged to be drawn back by means of a screw, to regulate the tension on both the hauling ropes.

Owing to the great elevation at which most of the stations are situated, the erection of the works was difficult and expensive. The carriage of the ropes up the mountain was especially so; their total weight was about 30 tons, and it had to be divided into coils of 20 cwt. each, as it was impossible to take up by cart a heavier weight.

In conveying these 20-cwt. coils to the upper parts of the line five horses were required to each, and only one coil per day could be delivered. The transport of the machinery, carriers, &c., was equally difficult and expensive. In building the masonry saddles, owing to the frequent occurrence of frost at night, even during the earlier part of the autumn, it was impossible to place reliance on the mortar used, and the masonry saddles were therefore strengthened with massive timber trestles, fixed round the stonework, which assisted them in taking part of the vertical strain. On a future occasion, in such a situation, it would be advisable to use timber trestles only. By arranging the junctions of the adjoining sections the strain of one balanced to a considerable extent that of the other, and by the anchorage of the fixed ropes of each of these sections to the same foundation beam, which was placed under the saddles, and also strongly bolted down to the rock, the weight of the masonry materially increased their security.

As the inclines joined one another at a horizontal angle, and on very confined spaces of ground, it was found necessary to transfer the contents of the carriers from one section to the next by small tip wagons running on a short and slightly inclined rail between the point where the loaded carrier stopped to discharge to that where the empty carrier stood at the top of the adjoining section. These wagons ran easily with the assistance of one man, who, when he had discharged the contents into the empty carrier, pushed it back into its place, ready to receive the contents of the next loaded one.

There was, of course, a similar arrangement on each side of each station; had it been possible to obtain better and more spacious sites for the stations, the usual arrangement would have been adopted of placing the anchorages so that one carrier could tip its contents direct into the empty carrier on the adjoining section, and the lower ends of the fixed ropes could have been anchored by means of weights.

In working these inclines it was necessary to have three men at each station; one man at the brake gear, and the other two men attending to the emptying of the loaded carriers and the transmission of their contents to the empty carriers on the next section. The man at the brake had an uninterrupted view of the whole section. The speed at which the carriers are allowed to run is about 25 miles per hour; when the brakesmen had become accustomed to their duties, they could regulate this speed to a nicety, and bring the carriers to a standstill at the proper points with perfect smoothness and accuracy.

The quantity of ore which can be transported by these inclines depends, of course, on what can be got over the longest section; and while, owing to the exigencies of the route, it was necessary that the sections should vary greatly in length, it was attempted to equalise their carrying capabilities, by making the longer sections steeper than the shorter ones, thus enabling the carriers to be run on the former at a higher speed. To some extent this was successful. In putting up a series of inclines, such as those now described, it will be advisable to equalise, as far as possible, the carrying powers of each section.

The amount of ore which has been regularly brought down by this system has been from 70 to 80 tons per day, but if sufficient mineral were provided, 100 tons per day could be transported. A trial with the 675 yards section, before the men had become thoroughly acquainted with its working, proved that 12 tons per hour could be taken down. The cost of carriage is about 2*s.* 0*d.*

per ton, exclusive of maintenance, which may be taken at 1*s.* 6*d.* per ton, or a total cost of 3*s.* 2*d.* The maintenance charge at these works will be exceptionally heavy, owing to their very exposed situation, and to the fact that for two months of the winter at least no work can be done, the plant meanwhile being exposed to the full deteriorating action of the weather.

By this ropeway the transport of mineral has been carried on without stoppage while the roads were buried in snow to a depth of several feet. The works have thus been supplied with ore for a much longer portion of the year than would have been possible by any other means of transport.

The cost of the whole work was about £5,000, of which only £2,200 were for the materials, the balance being for customs duty, freight, delivery from the nearest railway, 25 miles distant, cartage up the mountain, and erection.

The work was erected in the nine months from August to April, during six of which only could work be efficiently carried on, and in the remaining three months the weather and other causes prevented progress. Had the work been commenced earlier in the summer, it could probably have been completed in five months, and much of the erection would have been of far better quality.

SINGLE FIXED ROPE SYSTEM.

The second example of wire-rope transport on fixed ropes is a short length erected at the Nine Elms Works of the London Gas Light Company.

It was required to provide a means of transporting 24 tons per hour of gas coal across a dock in the above works to supply one of the retort houses. The point from which the coal was to be taken was about 12 feet above the ground, and it was required to deliver it into a hopper at a level of about 35 feet, the distance across the dock being 450 feet, and the incline consequently about 1 in 19 against the load. The company's engineer and manager, Mr. Robert Morton, M. Inst. C.E., requested the Author to prepare a scheme for his consideration for doing this by wire-rope transport, and finally the arrangement shown by Figs. 8 and 9, Plate 4, was adopted.

It consists of a single rope of crucible steel wire, of 40 tons breaking strain, stretched across the dock. The upper end is fixed to a timber framing, attached to the retort house at about 45 feet above the ground, the attachment on which is tied back by another wire rope, exactly in the same line as that over the dock, the end of which is anchored to the opposite wall of the house near the ground. The lower end of the rope across the dock is held by a weight of 4 tons, acting on the double purchase system, which thus exerts a strain of about 8 tons; by this means the strain on the rope is constant, whether the loaded truck is running on it or not. The truck is made of iron, and holds about 17 cwt. of coal; it is provided with a curved hanger, fitting into a running head which rests on a fixed rope. By a simple arrangement of a lever and catch, the bottom of the truck is let fall, and discharges its contents; the lever and catch are placed on the side of the truck, and thus the attendant who stands at the delivery terminal can empty the truck and replace the bottom with very little effort and loss of time. At the lower or loading end the truck runs off the rope on to a rail, on which it stands under the door of a hopper containing the coal to be transported. This is let into the truck by a sliding door conveniently worked. The truck is made to stand on the rail under the hopper, in order that it shall be supported rigidly, and at the same height during this operation, which it could not do had it remained on the rope. When loaded, it is drawn across to the discharging end, hanging on the fixed rope by means of the running head, at a speed of 5 miles per hour, up a nominal incline of 1 in 19, but owing to the bend of the rope this is often as much as 1 in 10. The running head which has been referred to is formed of two strong iron plates, carrying between them, one near each end, two deeply-grooved cast-iron wheels, about 9 inches in diameter on the tread, and made to fit the fixed rope. The edges of their rims are turned true, so as to run on the rail under the loading hopper before referred to. These wheels are carried on steel pins fitted between the wrought-iron plates, through which, between the wheels, the curved hanger attached to the truck also passes.

This head with its suspended truck is moved along the fixed rope by a small crucible steel wire rope of about 4½ tons breaking strain, which passes round a horizontal drum fixed at the upper end of the line to the wooden frame which carries the attachment of the fixed rope, and is put in motion by a simple arrangement of driving gear at the lower end of the line. This driving gear consists of a horizontal wood-rimmed drum driven by bevel gearing, so arranged that it may be moved at 5 miles per hour in the forward, and at 10 miles per hour in the backward direction. The driving drum is fitted with two parallel grooves, and by means of a smaller drum placed at one side of it, the hauling rope may be made to pass twice round certain portions of its circumference, and thus increase its driving power. This contrivance also gives a means of taking up any small amount of stretch which may take place in the hauling rope.

The whole of the driving gear is carried on a substantial A-shaped wooden frame, and alongside it is placed a small engine of 6 nominal HP. to provide the motive force. All the handles which control the motion of the driving gear, as well as that of a powerful brake on the fly-wheel of the engine, and that by which the loading hopper door is opened, are brought to a convenient spot where the driver can stand, who thus, without moving from his place, has control over all. In case the engine, which is of Tangye's "Soho" type, and of very short stroke, should stop on its centre, a ratchet lever arrangement is placed on the end of the crank-shaft, so that the driver can move it off with ease. In working this ropeway it is found that 30 lbs. of steam will drive the engine at the required speed, thus giving 8 HP. actual. The labour employed when working to the full capacity is as follows:—One driver, one trimmer, and one man at the discharging end.

The method of proceeding is as follows: The truck having arrived under the loading hopper, the driver pulls up the door, and the bucket is filled, the trimmer with a shovel levelling the coal as it falls; the driver, shutting the hopper door, engages the forward motion of the driving gear, and the truck is drawn across to the discharging hopper, about 5 feet square, at the upper end of the line some 450 feet distant; the driver, putting on the brake, stops the motion, and on receiving a signal from the man at the upper end that he has emptied the truck and replaced the bottom, puts the backward gear in motion, and draws the truck back to the loading hopper at a speed of 10 miles per hour. In regular working the whole of the operations described occupy two minutes, and thus 30 runs are made in the hour. At a trial, however, it was found possible to load, transport, and empty, ten trucks in fifteen minutes, or about 30 tons per hour.

Since this line has been at work a small apparatus has been fixed to the driving gear, by which the driver can stop the truck exactly over the hopper. This was previously effected by placing a mark on the hauling rope, but owing to much of the work being done while it is dark, a more convenient arrangement was found advisable.

The labour is paid for at the rate of 0·88*d.* per ton. The renewal of ropes, wheels, and general maintenance, may be taken at 0·4*d.*, of which the maintenance of the wire ropes is 0·26*d.* In all, excepting fuel, which in this case is the gas coke on the premises, the cost of loading, transporting for 150 yards up an incline of 1 in 19, and discharging, is 1·28*d.* per ton. The cost of the machinery ropes and steam engine for this work was £340. The erection and the platforms were provided by the London Gas Light Company.

Such a ropeway is very suitable for transporting materials across a space where supports are inadmissible, such as ravines, rivers, from shore to a pier-head, or pontoon in deep water, &c. The loads carried may be as heavy as 20 or even 30 cwt. net., as it becomes, under such circumstances chiefly a question of the strength of the rope. The Author, some years ago, erected a similar means of transport over a valley 1,000 yards wide, without intermediate support, and in that case loads of 15 cwt. were moved.

The Author trusts that, by the examples he has given of three descriptions of wire-rope transport, he has shown the applicability of the system under circumstances where the use of any other means would be either costly or impossible, and in such cases he believes this system may be advantageously used.

This communication is accompanied by several drawings, from which Plate 4 has been prepared.

(*Paper No. 1805.*)

"Description of a Bucket Dredger in use at the Hull Docks, with the results of its working."

By Robert Aspland Marillier, M. Inst. C.E.

This dredger consists of an automatic bucket in two equal parts, worked by a steam crane, securely fixed upon a lighter of suitable dimensions, and is the invention of Messrs. Priestman Brothers. The bucket in general arrangement is somewhat similar to others which have been used to a limited extent for several years; but the means by which the two pieces are opened and closed are superior to those applied to any other buckets which have come under the Author's notice.

An ordinary steam crane is not suitable for working the bucket, which is operated by two chains, requiring therefore special arrangements. Each chain passes over a separate barrel on the crane, one being used for lowering the empty bucket, the other for closing and thereby filling it, and afterwards for raising the bucket with its contents.

The following is the mode of proceeding: To lower the empty bucket the lowering chain is held by the brake, and the lifting chain being set at liberty, the weight of the bucket causes it to open, in which state it is lowered on to the mud or other material to be raised. The lowering chain is then released, and the lifting chain hauled in. This is wound round a drum on a shaft fixed across the bucket, on each side of which are smaller drums with short chains attached to a cross-head, acting upon four levers attached to the sides of the bucket. The action of the lifting chain is first to draw down the cross-head by the side chains, which causes the bucket to close, forcing it into the mud. As soon as the bucket is closed it is raised to the required height, and then swung round over the barge into which the mud is to be deposited. Then, by reversing the action on the chains, namely, securing the lifting chain and releasing the lowering chain, the bucket is opened to the full extent, and the mud falls from it. During the time the bucket is being raised, the lowering chain, which is passed round several sheaves, is gathered in by a self-acting counterbalance weight hung on to the chain by sheaves on the upper part of it. One man at the crane controls the working of the bucket with ease.

One of these dredgers, with a bucket capable of containing about 1 ton of mud, has been in frequent use by the Hull Dock Company for upwards of two years, and has been found of great service in removing mud from situations inaccessible to dredgers of the ordinary construction. It has entirely superseded the bag and spoon formerly employed for this kind of work; and it is found that whilst the work is done by it with far greater rapidity, the cost is about one-sixth of that by the bag and spoon.

The cost of dredging of course varies according to the situation and the depth of water in which it is carried on; but the following instances will give a good idea of it. The first case was in the docks, and the second in one of the timber ponds, where, owing to the shallowness of the water, the work was frequently interrupted by the dredger grounding, and from other causes. Had it been possible to have carried on the dredging continuously the cost of labour would have been considerably reduced. The expenditure comprises the actual cost incurred in raising the mud and depositing it in hopper barges, viz., labour, coals, and stores. The labour employed and the wages of the men per week were: one engine-driver, 25*s.*; one fireman, 19*s.*; one man in charge of hopper barge, 24*s.*

	First instance.	Second instance.
Quantity of mud raised (tons)	6,447	8,250
Average depth of water (feet)	17	8
Number of days' work	16	52
Average time per day of dredger working (hours)	8	5·9
„ quantity of mud raised per hour (tons) .	50	26·5
Cost per ton for labour (*d.*)	1·366	1·45
„ „ coal at 13*s.* per ton and stores (*d.*)	·266	·57
Total cost per ton (*d.*)	1·632	2·02

The material raised consisted of mud, varying in consistency; some of it, especially that in the second instance, being very stiff and compact. In the foregoing calculations no allowance is made for interest on plant, nor for wear and tear. The cost of the latter is small, and that of the former can be readily calculated from the data given. Messrs. Priestman Brothers' present price for a crane with bucket similar to that employed for the above-mentioned work is £512. The crane employed was fixed to an old mud barge. The cost of a new and suitable barge would be about

£300 or £400, according to the dimensions, and the material used in its construction.

Before commencing the use of the bucket it was thought that there might be a considerable loss of mud from hard substances getting between the edges of the two equal parts and preventing them from closing. In practice, however, very little trouble has been occasioned from this cause, the bucket having frequently brought up pigs of iron, iron plates and bars, timber, and other hard substances, without serious inconvenience.

A modification of the bucket, of similar construction, but with strong curved steel arms instead of plates, and to which the makers have given the name of "grab," answers well in excavating material too hard to be removed by the bucket. This has been used successfully in excavating hard clay from its natural bed on dry land.

At present the Author believes that this dredger has not been employed for regular dredging, but he does not see any reason why, if suitably arranged, it should not be so used. The first cost and the wear and tear of a dredger on this principle will certainly be much less than that of one of the ordinary description capable of doing a similar amount of work, the working parts being fewer, and the weight of the former much less than of the latter.

The communication is accompanied by a tracing, reproduced in Plate 5.

(*Paper No. 1758.*)

"Experiments on a New Form of Module for Irrigation Purposes."

By John Lewis Felix Target, M. Inst. C.E.

The want of a suitable apparatus for the exact delivery of measured quantities of water at the Irrigation Works, Jamaica, induced the Author to construct a new form of module adapted to deliver a constant quantity under variable heads.

Modules of different kinds have from time to time been used, and several were described in a Paper on Irrigation in Spain,[1] by Mr. G. Higgin, M. Inst. C.E. Among these Lieutenant Carrol's module, which has been tried by the Author, appeared to be the best; but it leaked considerably, and in proportion to the head of water, especially at that part or joint against which the drum or valve revolves. Moreover it cannot be made with a close-fitting joint without incurring considerable friction. The module established on the Henares Canal is in principle similar to the Milanese module, but it does not provide for variable heads; and the Ribera module could not be conveniently adapted to any existing canal without loss of head. It was with a view to construct a module specially for the delivery of small quantities of water, say from 100 to 2,000 gallons per minute, with the least possible loss of head and leakage, that the present apparatus, which may be termed a self-acting loose-valve module, was devised.

It consists of a cylindrical divergent cast-iron tube, A B C D, which may be of various diameters, but the same proportion must always be observed as indicated in Figs. 1 and 2. This form has been ascertained, by experiment, to be the most favourable one for the delivery of the largest quantity of water through tubes of equal diameters. The delivery is also capable of a great variety of adjustment, by changing the position of the loose plug-valve E, which resembles a hollow truncated cone, and can be made either of sheet copper or of galvanised sheet iron. If the diameter of the cast-iron tube at A B is 5 inches, the largest diameter of the truncated cone will also be 5 inches, less, say, $\frac{1}{16}$ inch, to allow of its being introduced at either end of the tube. The truncated cone, loose plug valve, is perforated at both ends and is traversed by an iron rod F with a screw tapped on the greater part of its length, so as to enable the valve to be screwed backwards or forwards, and adjusted to deliver the exact quantity of water

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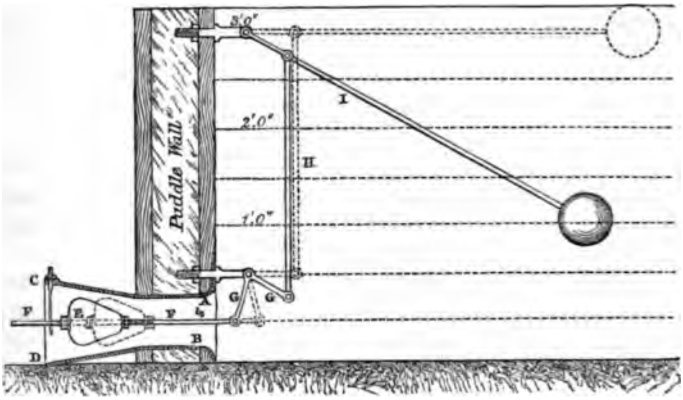
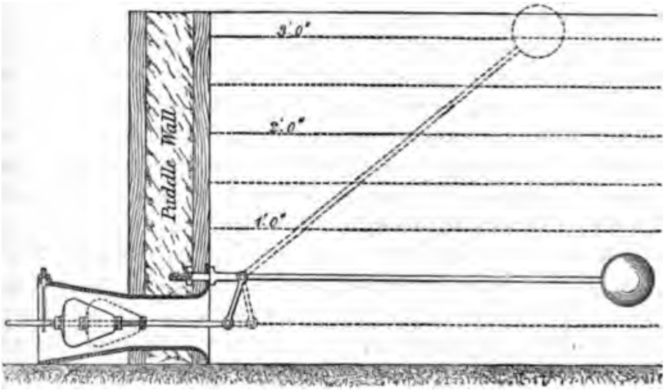
[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxvii., p. 483.

Fig. 1.



Module with Crank Lever, Ball Float for Deep Canals.

Fig. 2.



Module with Crank Lever, Ball Float for Shallow Canals.

through the module that may be desired. This range of action, however, is limited, and to ensure a proper working of the apparatus, ought not to exceed 3 inches. A 4-inch module can be adjusted to deliver from 120 to 250 gallons per minute; a 5-inch, from 280 to 400 gallons; a 6-inch, from 400 to 650 gallons, and so on. The iron rod F is connected to a wrought-iron bell-crank G, having arms of the same length as the diameter of the module. This bell-crank is attached by a rod H to a lever I, upon the end of which there is a spherical hollow copper ball of 1 inch larger diameter than the module. For modules of 3 to 6 inches in diameter, the float can be fixed to the end of one of the arms of the crank G, in which case the arm is lengthened to 3 feet, and to 4 feet with a 6-inch module. If the depth of water in the canal varies only from 1 foot to 2 feet, then this latter system is preferable; but for canals of greater depth, the plan first described, with hanging rod I, made of various lengths to suit the depths of water, is better. The most suitable working position for the plug-valve is with a space of about 1 inch between the largest diameter of the valve and the inside of the tube, when the action or pull of the crank, communicated by the float and lever, will be about 3 inches in length. The action will be readily understood from Figs. 1 and 2. The sectional space in the tube is diminished as the head of water increases and the float is raised, the contrary taking place when the float falls.

This module was placed in a conduit built in masonry 2 feet in breadth by 3 feet in depth with a fall of 1 in 100. The water was admitted with regularity into the conduit by an iron sluice-gate worked by rack and pinion; and an iron grating, with the bars 1 inch apart, was placed between the module and the inlet gate, to check the velocity of the current and to prevent sticks or rubbish from entering the module. The quantities of water passed were measured by a thin sheet-iron weir-notch, 18 inches broad, fixed across the conduit at 35 feet below the module. All measurements for head of water over the weir were taken at a distance of 5 feet above by a graduated scale divided into inches and eighths of an inch. Below the weir, on the same conduit, a gauging tank was built in masonry, having a superficial area of 70 square feet. It was fitted with an outlet wooden drop-gate running in a grooved frame, and the heights of the water were read off a levelling staff, time being recorded from a watch having a second's hand. The mean of three measurements was taken for each experiment whenever these were checked by the gauging tank.

The following are the results of some experiments on 4-inch, 5-inch, and 6-inch modules:—

EXPERIMENTS with a 4-inch SELF-ACTING LOOSE-VALVE MODULE under HEADS VARYING from 9 inches to 3 feet on the centre of the ORIFICE.

No. 1.				No. 2.			
Head on Centre of Orifice.	Depth on Weir.	Discharge per Minute.	Observations.	Head on Centre of Orifice.	Depth on Weir.	Discharge per Minute.	Observations.
Ft. Ins.	Inches.	Gallons.		Ft. ins.	Inches.	Gallons.	
0 9	$3\frac{3}{8}$	272	Open module, plug valve removed, allowing a full flow through 4-inch tube.	0 9	2	133 Variation 12.	Minimum range or delivering capacity of module, with plug valve acting.
1 0	$3\frac{5}{8}$	319 Variation 169.		1 0	$2\frac{1}{8}$	145	
1 6	$4\frac{1}{8}$	365		1 3	$2\frac{1}{8}$	145	
2 0	$4\frac{3}{8}-\frac{1}{2}$	425		1 9	$2\frac{1}{8}$	145	
2 6	$4\frac{5}{8}$	454		2 3	2	133	
3 0	$4\frac{7}{8}$	488					
No. 3.				**No. 4.**			
0 9	$2\frac{6}{8}-\frac{1}{2}$	212–5	Maximum range or delivering capacity of module, with valve screwed back 2 ins. from position of No. 2 experiment.	0 9	$2\frac{5}{8}-\frac{1}{2}$	206	Experiment No. 3 repeated at maximum range.
1 0	$2\frac{7}{8}-\frac{1}{2}$	234 Variation 23.		1 0	$2\frac{7}{8}$	226 Variation 15.	
1 6	3	241		1 6	3	241	
2 0	$3\frac{1}{16}$	249		2 0	$2\frac{7}{8}-\frac{1}{2}$	234	
2 6	3	241		2 6	$2\frac{7}{8}-\frac{1}{2}$	234	
3 0	$2\frac{7}{8}$	226		3 0	$2\frac{7}{8}$	226	

The variations of discharge in the three last experiments with the valve acting was only 8, 9, and 6 per cent. of the total quantity; whereas with the open tube, and without the valve, it amounted to 34 per cent. with heads varying from 1 foot to 3 feet in the canal.

All quantities were calculated by the formula $G = d \times \sqrt{d} \times l \times 2 \cdot 67$ (see Table 19 in Box's "Practical Hydraulics"), the contraction of the weir being taken into consideration according to Francis' experiments, which reduce the breadth of the weir 0·2 inch for each inch in depth of overfall.

EXPERIMENTS with a 5-inch SELF-ACTING LOOSE-VALVE MODULE under HEADS VARYING from 1 foot to 3 feet.

No. 5.

Head on Centre of Orifice.		Depth on Weir.	Discharge per Minute.		Observations.
Ft.	ins.	Inches.	Gallons.		
1	0	4⅜	454	Variation 353.	With open tube, the valve being removed. The surface velocity in canal for 1 foot head was equal to 1 foot per second. Do. for 3 feet = 1·43 foot.
1	6	5⅛	582		
2	0	6	659		
2	6	6⅜	760		
3	0	6⅞	807		

Checked by tank measurement.

1	0	4⅜	457	By weir.
			441	By tank.
Difference			16	

No. 6.

Head on Centre of Orifice.		Depth on Weir.	Discharge per Minute.		Observations.
Ft.	ins.	Inches.	Gallons.		*v* = surface velocity at 5 feet above weir.
1	0	3⅝	271	Variation 46.	Position of valve screwed up to the minimum range.
1	6	3¾	287		
2	0	3¾	287		
2	6	3⅛	257		
3	0	3	241		*v* = 0·80 foot per second at 3 feet head.

Checked by catchpit measurement.

1	0	4⅛	385	By weir.
			382	By catchpit.
Difference			3	

No. 6 bis.

1	0	3⅝–½	279	Variation 16.	No. 6 experiment repeated.
1	6	3¾	287		
2	0	3¾	287		
2	6	3⅝	271		
3	0	3⅝	371		*v* = 0·80 foot per second at 3 feet head.

No. 7.

1	0	4$\frac{1}{16}$	377	Variation 8.	Position of valve altered and screwed back to the maximum range, a distance of 2½ ins. along the rod.
1	6	4⅛	385		
2	0	4⅛	385		
2	6	4⅛	385		
3	0	4⅛	385		

No. 8.

1	0	4⅛	385	Variation 33.	Experiment No. 7 repeated; valve in same position. *v* = 0·91 foot per second at 2 feet head.
1	6	4¼–½	413		
2	0	4¼	418		
2	6	4¼	418		
3	0	4⅛	385		

Checked by tank measurement at 2 feet head.

2	0	4¼	418	By weir.
			429	By tank.

No. 9.

1	0	3⅞	350	Variation 32.	Valve altered to an intermediate position between the maximum and minimum range.
1	6	4	367		
2	0	4	367		
2	6	3⅞–½	359		
3	0	3⅝	335		

Checked by tank at 2 feet head.

..	..	366	

EXPERIMENTS with a 5-inch SELF-ACTING LOOSE-VALVE MODULE under HEADS VARYING from 1 foot to 3 feet—*continued.*

No. 10.

Head on Centre of Orifice.		Depth on Weir.	Discharge per Minute.	Observations.
Ft.	Ins.	Inches.	Gallons.	
				No. 9 renewed.
1	0	$3\frac{6}{8}-\frac{1}{2}$	345 339	Checked by tank.
Difference			6	Velocity 0·80 foot per second.

No. 11.

Head on Centre of Orifice.		Depth on Weir.	Discharge per Minute.		Observations.
Ft.	Ins.	Inches.	Gallons.		
1	0	$3\frac{6}{8}-\frac{1}{2}$	345	Variation 220.	Valve in same position as experiments Nos. 9 and 10, but fixed or rendered immovable at 1 ft. head, so that it could not be worked by float lever.
1	6	$4\frac{2}{8}$	402		
2	0	$4\frac{5}{8}$	465		
2	6	$5\frac{1}{8}$	526		
3	0	$5\frac{3}{8}$	565		

No. 12.

Head on Centre of Orifice.		Depth on Weir.	Discharge per Minute.		Observations.
1	0	$4\frac{4}{8}$	436	Variation 187.	Substituted a 4-inch valve for the 5-inch, and screwed up to the same position as for experiment No. 8 with 5-inch valve. $v=1\cdot18$ ft. per sec. at 3 feet head.
1	6	$4\frac{7}{8}$	488		
2	0	$5\frac{4}{8}$	582		
2	6	$5\frac{5}{8}$	602		
3	0	$5\frac{6}{8}$	623		

No. 13.—With 5-inch module, open tube-valve removed; quantities checked by tank measurement; area of gauge tank 70 square feet.

Head on Centre of Orifice.		Depth on Weir.	Discharge per Minute.	Observations.
				Experiment No. 5 renewed and checked.
1	0	$4\frac{4}{8}$	436 445	$v=0\cdot83$ ft. per sec. By tank.
2	0	$5\frac{7}{8}-\frac{1}{2}$	649 663	$v=1$ ft. per second. By tank.
3	0	$6\frac{5}{8}$	760 783	$v=1\cdot25$ ft. per sec. By tank.

In calculating the quantities discharged through the weir-notch, the formula previously quoted was applied, but no allowance has been made for the velocity of approach to the weir, as is usual. If this had been taken into account, all the quantities would, for the several surface velocities varying from about 0·50 foot to 2 feet per second, have had to be increased from 8 to 10 per cent. It will also be noticed that in nearly all the experiments the tank measurement was slightly in excess of that by the weir, which if anything would require to have been more reduced than otherwise.

The surface velocity was nearly uniform in the 35-feet space between the module and the weir up to within 10 feet of the weir, when it increased as follows, attaining, say, a mean of 1 foot per second for the first 5 feet nearest the weir, and 0·55 foot for the preceding 5 feet.

EXPERIMENTS with a 6-inch SELF-ACTING VALVE MODULE under HEADS VARYING from 1 foot to 3 feet.

No. 14.

Head on Centre of Orifice.		Depth on Weir.	Discharge per Minute.		Observations.
Ft.	ins.	Inches.	Gallons.		
1	0	$6\frac{1}{8}$	680	Variation 537.	With open module valve removed, allowing a full flow through tube.
1	6	$7\frac{3}{8}$	865		$v=1$ ft. per second for 1 foot head.
2	0	8	991		$v=1\cdot66$ ft. per sec. for 2 feet head.
2	6	$8\frac{5}{8}$	1102		$v=2$ ft. per second for 3 feet head.
3	0	$9\frac{3}{8}$	1217		

No. 15.

Head on Centre of Orifice.		Depth on Weir.	Discharge per Minute.		Observations.
Ft.	ins.	Inches.	Gallons.		
1	0	$4\frac{7}{8}$	488	Variation 96.	Valve at about the maximum range.
1	6	$5\frac{2}{8}$	546		
2	0	$5\frac{1}{4}$	582		
2	6	$5\frac{6}{8}-\frac{1}{8}$	623		
3	0	$5\frac{6}{8}$	623		

No. 16.

Head on Centre of Orifice.		Depth on Weir.	Discharge per Minute.		Observations.
Feet.	Inches.	Inches.	Gallons.		
1	0	$4\frac{1}{8}$	358	Variation 96.	Minimum range, valve screwed up 3 inches along the rod from its position in experiment No. 15 for maximum range.
1	6	$4\frac{4}{8}$	436		
2	0	$4\frac{5}{8}$	454		
2	6	$4\frac{5}{8}$	454		
3	0	$4\frac{5}{8}$	454		

These and other experiments with a 6-inch module tend to show that the least variations and the best results are obtained where the annular space between the largest diameter of the valve and the inside of the tube is from 1 to $1\frac{1}{2}$ inch, and it should not in a module of any size exceed $1\frac{1}{2}$ inch. With the 4-inch module it was found to work well with an annular space varying from 1 inch as a maximum to $\frac{1}{2}$ inch for a minimum range.

To find the number of gallons that a module of given dimensions is capable of discharging; suppose the position of the valve in the tube to be that due to 1 foot per head of water on the centre of the module; from the sectional area of the tube taken on the line of the greatest diameter of the valve deduct the sectional area of the greatest diameter of the valve. The difference will be the area of a circular ring, of which find the diameter of a circle of equivalent area. Then with this diameter calculate the required discharge under 1 foot head as for the theoretical discharges for round apertures, substituting the coefficient 14 for that of 16·3 *in the ordinary formula* $G = \sqrt{H} \times d^2 \times 16\cdot3$.

For metrical measurement, instead of formula $Q = 0 \cdot 82 A \sqrt{2 g H}$, substitute $Q = 0 \cdot 853 A \sqrt{2 g H}$, which will give the results in litres. The module could evidently be increased in size, and there is no reason why it should not give as satisfactory results for a tube 12 inches in diameter as for one of 4 inches. It works equally well with clean or muddy water, and does not choke with mud, gravel, leaves, or any object below an inch in diameter; however, it should, like all other appliances of the kind, be protected by a suitable grating.

EXPERIMENTS with the SAME 6-inch SELF-ACTING LOOSE VALVE, but with a CIRCULAR 6-inch APERTURE in a THIN SHEET-IRON PLATE INSTEAD of the CONICAL DIVERGENT TUBE.

No. 17.

Head on Centre of Orifice.		Depth on Weir.	Discharge per Minute.		Observations.
Ft.	Ins.	Inches.	Gallons.		
1	0	$4\frac{1}{8}$	385	Variation 295.	Without valve.
1	6	$4\frac{7}{8}$	488		
2	0	$5\frac{3}{8}$	562		
2	6	$5\frac{6}{8}$	623		
3	0	$6\frac{1}{8}$	680		

Checked by tank measurement at 2 feet head.

By weir .	562	
„ tank .	538	Mean of three experiments.
Calculated	509	By formula $G = \sqrt{H} \times d^2 \times 10$. To equal the tank measurement the coefficient 10 ought to be 10·5. The excess over the calculated quantity was probably due to the 12 inches of short tube in advance of the plate, the contraction not being so complete as if the short channel of approach had been 12 inches broad instead of 8 inches.

No. 18.

Head on Centre of Orifice.		Depth of Weir.	Discharge per Minute.		Observations.
Ft.	Ins.	Inches.	Gallons.		
1	0	$3\frac{5}{8}$	317	Variation 76.	With valve at maximum range.
1	6	4	367		
2	0	$4\frac{1}{8}$	385		
2	6	$4\frac{1}{8}-\frac{1}{2}$	393		
3	0	$4\frac{1}{8}-\frac{1}{2}$	393		
1	0	$3\frac{4}{8}$	302	Variation 116.	Valve as above, but with thin plates placed in front of the puddle wall at *b*.
1	6	$3\frac{7}{8}$	350		
2	0	$4\frac{1}{8}$	385		
2	6	$4\frac{2}{8}$	402		
3	0	$4\frac{3}{8}$	418		

EXPERIMENT AS ABOVE, but with a 5-inch VALVE and a 5-inch CIRCULAR APERTURE in THIN PLATE PLACED in FRONT of the PUDDLE WALL at *b b*.

No. 19.

Head on Centre of Orifice.	Depth on Weir.	Discharge per Minute.	Observations.
Feet. Inches.	Inches.	Gallons.	With open 5-inch aperture, the valve being removed.
1 0	$3\frac{1}{8}$	257	By weir.
Checked by . . .		253	„ tank.
		250	„ calculation and formula $G = \sqrt{H} \times d^2 \times 10$.
2 0	4	367	„ weir.
Checked by . . .		362	„ tank.
		353	Calculated.
3 0	$4\frac{5}{8}$	454	By weir.
Checked by . . .		449	„ tank.
		443	Calculated.

Variation of above, 449 − 250 = 199 gallons.

No. 20.

1 0	$2\frac{7}{8}-\frac{1}{2}$,	234	Variation 30.	With valve working in the aperture at maximum range.
1 6	3	241		
2 0	$3\frac{1}{8}-\frac{1}{2}$	264		
2 6	$3\frac{1}{8}-\frac{1}{2}$	264		
3 0	$3\frac{1}{16}$	249		

From the above it will be seen that the valve acts nearly as well through a thin plate as in the conical divergent tube, but only in one position, and does not admit of being screwed up to so great a range as in the tube; it cannot, therefore, be so susceptible of nicety of adjustment for the passage of any given quantity of water.

In making the above experiments and calculating the quantities of water passing through the weir-notch, the velocity of approach was at first taken into consideration; and at 1 foot per second increased the measurements to about 8 per cent. The results with this addition were invariably found to be considerably in excess of the checked measurements by the gauge tank, which were frequently repeated and carried out with the greatest care. As these latter in nearly all cases coincided with the former, and were if anything already slightly in excess of the weir measurement, without adding the quantity due to the velocity of approach, it would appear that for a small weir-notch and channel of approach of this description, with velocities of approach varying from 1 foot to 2 feet per second, this ought to be omitted in making calculations by the ordinary formula. In weirs of small breadth it is important to take the contraction of the weir on two sides into consideration, as by Francis' rule,[1] up to about 9 inches depth of water over the weir. Above 9 inches this rule is not so correct in its application as for more shallow depths.

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[1] *Vide* "Practical Hydraulics," by Thomas Box. Article 76.

(*Students' Paper No. 128.*)

"The Internal Corrosion of Cast-Iron Pipes."[1]

By MATHEW BUCHAN JAMIESON, Stud. Inst. C.E.

THE following remarks deal with the internal corrosion of cast-iron water-carrying pipes, as observed in the City of Aberdeen, with estimates of the cost of getting rid of the obstruction, and as to the loss of space and pressure due to the same.

I. GENERAL DESCRIPTION.

The rust is invariably of a brown colour, presents an uneven surface, and in many cases appears to be formed in distinct layers If taken from a pipe after long continued use it is exceedingly hard, and does not, unless disturbed, affect the colour or purity of the water. When dried it becomes crisp, and is easily ground to a fine powder of a yellowish-red tint.

The pipes are usually in one of two conditions. The first is that in which the iron is directly exposed to the action of the water; the second, that in which the iron is protected by a coating of asphalt. In the former, the corrosion commences and continues uniformly distributed, growing with considerable rapidity; while in the latter it appears in detached carbuncles or knots, at points where the protective coating is weakest; these gradually increasing and enlarging coalesce, and the rust then grows as rapidly as if no preparation had been made to resist it. This chemical change may commence at once in a pipe not specially prepared to resist it, but seven to nine years usually elapse before it has any appreciable effect on one coated with asphalt.

The carbuncles from a pipe coated with asphalt usually have a cavity in the under surface, being attached by their edges only. This form may be caused by the blistering of the asphalt coating through the collection of air or other gases, thereby preventing the central portion of the carbuncle from touching the iron (Fig. 1).

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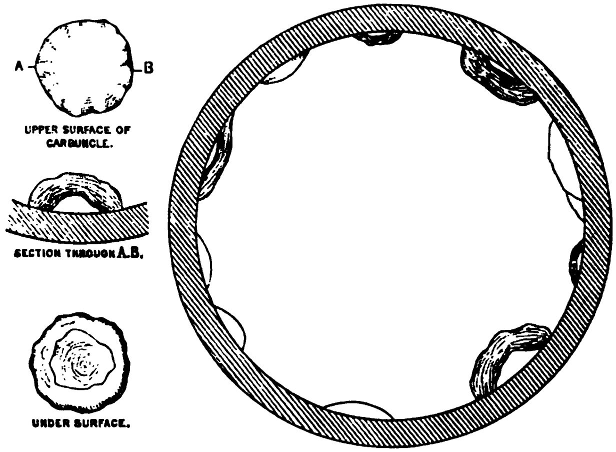
[1] This communication was read and discussed at a meeting of the Students on the 11th of February, 1881, and has been awarded a Miller prize.

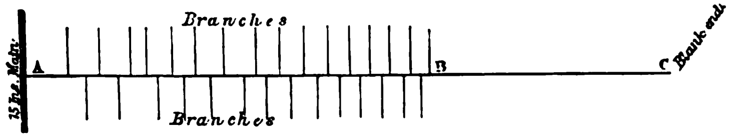
FIG. 1.



Asphalt Coated Pipe, 6 inches in diameter.
Scale, one-third full size.

As an illustration of the fact that the corrosion is proportional to the volume of water passing along a pipe and the commotion existing therein, it is found that while main pipes, through which water is constantly passing, are nearly filled with rust, their fire-cock branches, through which it but seldom flows (though they are constantly full) are comparatively clean. The following example shows the difference in the amount of corrosion in the same pipe. The pipe A B C, Fig. 2, terminating in a closed end at C, had no branches between B and C, while from A to B there were about thirty branches drawing off a large supply which gradually diminished in quantity towards B. When the pipe had been forty-five years in continual use, it was inspected and found almost filled with rust at A, which gradually decreased, till between B and C the pipe was almost in its normal condition.

FIG. 2.



Pipe A B C.

II. Chemical Composition.

The City Analyst, in reporting on the water supplied to Aberdeen, said:—"Water containing 3 grains of the usual kinds of solids per gallon is of necessity soft, very suitable for washing, and unlikely to form much permanent deposit. But while, by the use of such soft water the tendency to incrustation of boilers is very much reduced, corrosion of boilers by means of the oxygen, and especially of the carbonic acid dissolved in water, is more likely to take place than by the use of hard water, there being little mineral in soft water by which this acid can be neutralised. . . . . The softness of the water is owing to the insoluble granitic character of the district through which the Dee and its tributaries pass."

The solids present in the water amount to 2·94 grains per gallon, or 42 parts per million, and are in the following proportion:

	Grains.		Grains.
Sulphuric anhydride	0·333	Iron oxide and alumina	0·033
Nitric „	0·056	Silica	0·253
Chlorine	0·798	Carbonic anhydride, sodium, potassium, and organic matter	0·952
Lime	0·336		
Magnesia	0·179		

Hardness = 1·11.

The following statements are also by the City Analyst, viz.:

No. 1.—Analysis of Rust from a Pipe 4 inches in diameter, which had been Twenty-one years in continual use; not coated with Asphalt.

	Per cent.		Per cent
Volatile or combustible matter	16·62	Magnetic iron oxide	32·47
		Iron oxide	9·04
Sulphuric anhydride	0·60	Insoluble sandy matter.	41·27
Phosphoric „	slight trace	Lime	trace

No. 2.—Analysis of Rust from a Pipe 10 inches in diameter, which had been Fifteen years in continual use; coated with Dr. Angus Smith's preparation of Asphalt.[1]

	Per cent.		Per cent.
Volatile or combustible matter	18·05	Magnetic iron oxide	0·36
		Iron oxide	37·55
Sulphuric anhydride	1·08	Insoluble sandy matter	42·78
Phosphoric „	trace	Lime	0·18

These samples do not materially differ, except in the condition of the iron, No. 1 being chiefly magnetic, while only a minute quantity of the iron of No. 2 is in that state.

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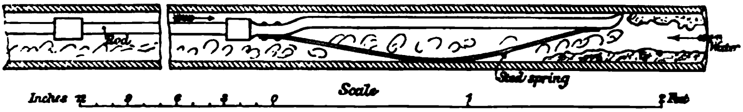
[1] The composition of the varnish is given in the patent taken out by Dr. Robert Angus Smith, F.R.S. The mode recommended for use should also be attended to.

III. METHODS OF EXTRACTION.

Three methods have been tried to extract or get rid of the rust. The first was the clumsy, although sure, method of taking up the pipes, heating them, and thereby detaching the rust. This mode is not now practised, from the necessity of having to substitute a new main for the one taken up. The second is the extraction by manual labour, which is suitable for pipes from 2 to 5 inches in diameter, and in carrying it out the following operations must be performed. The lowest level in the pipe being selected, the ground for 2 feet below its level is excavated so as to enable from five to eight men to work in the excavation; a portion of the pipe from 9 to 10 feet long is cut out, and, if possible, a connection made between the bottom of the excavation and an adjoining sewer. If that cannot be done, pumping has to be resorted to. Before the pipe is cut, the water is shut off above the level of the portion to be cleaned, and allowed to escape at a cock below the point where it is to be cut. The tool used for detaching the rust (Fig. 3) has the cutting edge of steel, and of the same curvature as the internal diameter of the pipe, against which it is pressed by the action of a steel bow or spring, so placed as to require some force for the insertion of the tool. The tool or scraper is inserted into the pipe, and a connecting rod, of $\frac{3}{4}$ inch malleable iron tubes in lengths of 6 feet, is joined on. It is now driven forward by the men in the excavation, and drawn backwards, accompanied by a rotatory motion so as to clean the entire circumference. The whole length of the pipe becomes gradually cleaned unless a bend should occur, when a fresh excavation has to be made, the pipe cut and operations commenced afresh. Coincident with the scraping a stream of water is made to run down the pipe, thus carrying the detached rust into the excavation from which it is removed.

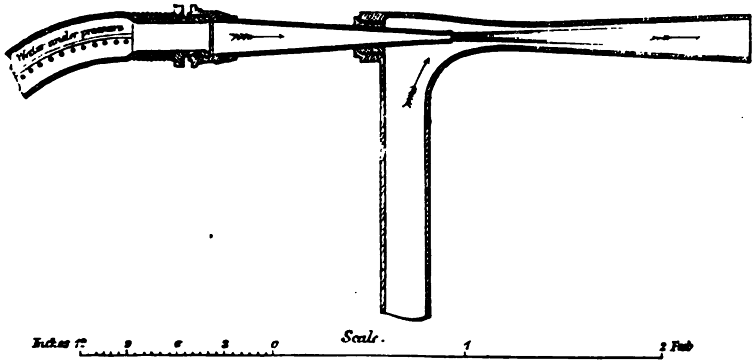
FIG. 3.



Machine for Cleaning by Manual Labour.

A jet pump (Fig. 4) is employed, both in this method and in that next to be described, to keep the excavation clear of the water falling into it from the pipe.

Fig. 4.



Jet Pump.

The following Table gives the cost of cleaning various pipes by this method, including the maintenance of the streets opened or destroyed by the operations. The men were paid one-third more than the usual rate (inserted as additional time), as the work was carried on at night to avoid public inconvenience.

Table I.—Cost of Cleaning Water-mains by Manual Labour.

No.	Age of Pipe.	Internal Diameter of Pipe.	Length Cleaned.	Approximate Amount of Rust per Lineal Yard.	Total Cost of Operation.	Cost per Lineal Yard.
	Years.	Inches.	Yards.	Cubic Inches.	£. s. d.	d.
1	9	3	127	20	1 9 0	2·74
2	24	3	130	70	1 19 1	3·60
3	25	3	323	73	4 7 6	3·25
4	31	3	200	81	3 2 6	3·75
5	32	3	124	85	2 0 4	3·90
6	39	3	181	100	3 11 4	4·72
7	9	4	150	30	3 1 0	4·88
8	22	4	96	85	2 14 4	6·79
9	28	4	67	163	1 13 6	6·00
10	29	4	442	182	11 12 0	6·30
11	36	4	115	190	3 1 4	6·40
12	50	4	370	210	10 6 6	6·69
13	14	5	110	48	3 6 0	7·20
14	23	5[1]	543	194	26 0 0	11·48

d.
Average cost for 3-inch pipes 3·656 per lineal yard.
" 4 " 6·176 "
" 5 " 9·340 "

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[1] In this pipe several obstructions occurred.

The following are the details of the cost of Nos. 4 and 12, Table I.:—

No 4.

3-inch pipe, length 200 yards.

		d.	£.	s.	d.
Time—					
6 hours,	foreman	at 7 =	0	3	6
26 „	junior do.	5 =	0	10	10
106 „	labourers	4 =	1	15	4
8 „	boy	2 =	0	1	4
Materials—					
2 new cast-iron collars			0	4	1
16 lbs. lead		2 =	0	2	8
2 „ rope yarn		4½ =	0	0	9
Naphtha, for lamps			0	0	6
Coals			0	1	0
Cartage			0	2	6
	Total		3	2	6

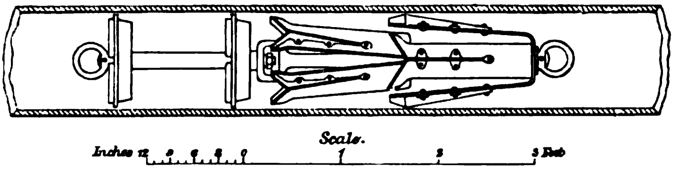
No. 12.

4-inch pipe, length 370 yards.

		s.	d.	£.	s.	d.
Time—						
34 hours,	foreman		at 7 =	0	19	10
78 „	junior do.		5 =	1	12	6
156 „	labourers		4½ =	2	18	6
125 „	„		4 =	2	1	8
10 „	boy		2 =	0	1	8
Watchman				0	10	0
Materials—						
3 yards 4-inch cast-iron pipe		2	10 =	0	8	6
3 cast-iron collars, 1 cwt. 2 lbs.		8	3 =	0	8	4½
40 lbs. lead		0	2 =	0	6	8
9 „ rope yarn		0	4½ =	0	3	4½
Naphtha				0	1	3
Cartage				0	5	0
Coals				0	3	0
Sundries				0	6	2
	Total			10	6	6

In the third method of cleaning pipes, the machine used was manufactured by Messrs. Kennedy and Co., of Kilmarnock. It consists of an iron rod to which are attached two pistons and two sets of scrapers, one in front of the other; the scrapers, the front set being smaller in diameter than the other, are each made up of four strips of steel, about $\frac{3}{32}$ inch thick by 2½ inches broad, and of equal length, sloping backwards from the rod to which they are attached, and at their outer terminations shaped and sharpened like the barbs of an arrow. This construction enables them to yield when coming into contact with a rigid projection, such as the nipple of a connection; and further the cutting diameter of each set may be altered by pressing in or pulling out the strips of steel. The pistons, which are of slightly less diameter than the pipe, are compound, and made up of three disks—one of iron, one of lead, and one of leather—the two last being cut into corresponding sectors and riveted firmly together. The pistons can easily be taken off the machine, and therefore, if it is thought advisable, one of larger or of smaller diameter may be readily substituted. This machine is illustrated in Fig. 5.

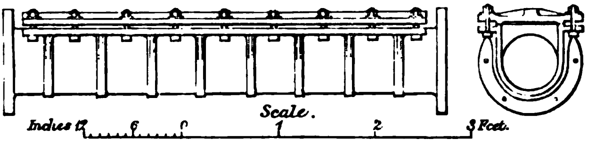
Fig. 5.



Machine for Cleaning by Water Pressure.

The addition of hatch-boxes (Fig. 6) is desirable, for by them not only is a permanent and easy access for subsequent examination obtained, but during any single operation the machine may be repeatedly and easily inserted and withdrawn. These boxes are of cast iron, and may be manufactured to suit any diameter of pipe. In all new works, hatch-boxes may, with advantage, be part of the system so as to be ready for use at any required time.

Fig. 6.

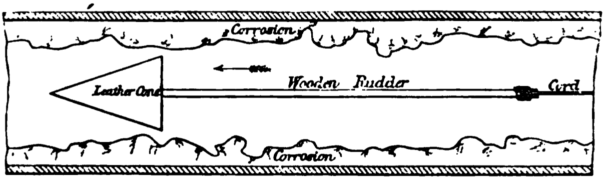


Hatch Box.

Having turned the water off the main, the hatch-box is fitted on at the upper end, and at the lower end the pipe is cut, and enough removed to let the machine be taken out. The machine is now inserted in the hatch-box and the lid bolted down; men are then stationed with improvised stethoscopes at distances of about 10 yards apart along the track of the pipe, the water is turned on, and, acting on the pistons, drives the machine forward. The noise of the advancing machine is communicated to each man in turn, who, as soon as it has passed, advances to a position ahead of his neighbours, and so on, thus forming a continuous line of observation. Any obstruction is in this manner immediately recognised and reported. Various expedients are tried to start the machine if it stops, such as shutting off the water for a few minutes and then suddenly turning it on, and this usually has the desired effect. The turbulent state of the water as it emerges tells whether or not the machine is in motion. The instrument having passed through the entire length of pipe, from which the water and rust have been removed, falls into the excavation at the lower end. It is advisable to pass the machine a second time through the pipe with the scrapers expanded and with larger pistons, after which the water is made to run till it emerges perfectly clear.

In pipes of 6 or 7 inches diameter, reduced by rust to about 5 inches, where stoppages of the machine would readily occur, progress is materially assisted by horses being yoked to an intervening chain. The passage of the chain along the pipe, a matter of some difficulty, is best effected by floating down a hollow leather cone with a wooden rudder about 18 inches long (Fig. 7), to which one end of a cord is attached, the other end being tied to the chain.

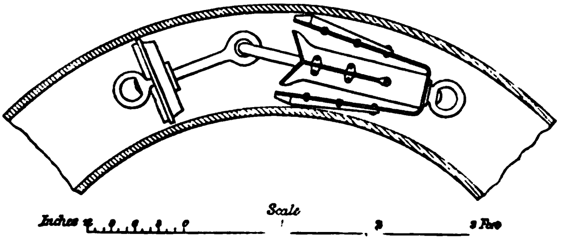
FIG. 7.



Floating Cone.
Scale, one-eighth full size.

The machine originally, owing to its length, could not be passed along bends in the pipes. To overcome this, one set of scrapers and one piston were taken off, and in place of the rigid iron rod, one with a flexible joint has been substituted. By this change the machine has been made to pass bends of a radius of 3½ feet. The construction of this modification is shown in Fig. 8.

FIG. 8.



Modification of Machine for Cleaning by Water Pressure.

Should progress be obstructed in spite of every means to move the instrument, the ground above must be excavated, the pipe cut, and the machine taken out.

If both conditions for rapid progress be fulfilled, viz., good pressure of water and little obstruction in the pipe, the machine may travel at the rate of about 6 miles an hour.

The operations must be carried on during the night, where the pipes are within the town, and in causewayed streets; in the former so as to cause as little inconvenience as possible to the public; in the latter so that carriage traffic may not be in the way of the speedy detection of obstructions.

TABLE II.—COST OF CLEANING WATER-MAINS by WATER PRESSURE.

No.	Age of Pipe.	Size of Pipe.	Length Cleaned.	Approximate Amount of Corrosion per Lineal Yard.	Total Cost of Operation.			Cost per Lineal Yard.	Remarks.
	Years.	Inches.	Yards.	Cubic Inches.	£.	s.	d.	d.	
1	10	6	539	210	19	18	0	8·86	Obstructions occurred, and machine had to be cut out of pipe.
2	20	6	240	334	7	4	0	7·20	Pressure of water not sufficient to put machine through without stoppages.
3	34	6	872	578	27	10	2	7·57	
4	15	7	1,500	138	9	13	8	1·54	Pipe coated with asphalt.
	Same pipe, with hatch-boxes				22	4	7	3·55	Do.
5	15	9	1,933	153	19	12	0	2·43	Do.
	Same pipe, with hatch-boxes				38	14	0	4·80	Do.
6	15	10	2,310	150	10	11	7	1·10	Do.
	Same pipe, with hatch-boxes				30	10	0	3·16	Do.
7	40	15	1,043	1,700	29	19	0	6·89	Clip - joints used instead of hatch-boxes. Hand pumping to free excavation of water.

	d.
Average cost of cleaning 6-inch pipes per yard . .	7·87

The following are the details of the cost of Nos. 3 and 6, Table II.:—

No. 3.

6-inch pipe, length 872 yards.

	d.	£.	s.	d.
Time—				
54 hours, foreman	at 7 =	1	11	6
324 „ junior do.	5 =	6	15	0
90 „ labourers	4¾ =	1	15	7½
108 „ „	4½ =	2	0	6
18 „ „	4¼ =	0	6	4½
414 „ „	4 =	6	18	0
46 „ causeway layer	5½ =	1	1	1
108 „ boy	2½ =	1	2	6
Materials—				
12 couplings and collars		2	16	7
112 lbs. lead	2 =	0	18	8
12 „ ropeyarn	4½ =	0	4	6
Naphtha		0	2	4
Coals		0	4	0
Sand		1	0	0
Carting		0	13	6
Total		27	10	2

No. 6.

10-inch pipe, length 2,310 yards.

		s.	d.	£.	s.	d.
Time—						
20 hours, foreman			7 =	0	11	8
30 „ junior do.			5½ =	0	13	9
30 „ labourers			5 =	0	12	6
60 „ „			4¾ =	1	3	9
120 „ „			4 =	2	0	0
30 „ „			4¼ =	0	10	7½
Materials—						
4 10-inch thimbles		9	0 =	1	16	0
Lead, 2 qrs.	per cwt.	14	0 =	0	7	0
Ropeyarn, 6 lbs.		0	4½ =	0	2	3
Paraffin, 2 gals.		0	7½ =	0	1	3
Coals, 1 cwt. 2 qrs.		1	0 =	0	1	6
Carting				2	0	0
Sundries				0	11	3½
Total				10	11	7
Two 10-inch hatch-boxes				19	18	5
Total with hatch-boxes				30	10	0

The above Table includes the cost of repairing streets injured by the operations, and the cost with and without hatch-boxes.

As it is hardly possible to meet with two cases exactly alike, the dissimilarity in the cost of cleaning the various pipes is to some extent accounted for. The thickness of the rust in the case of pipes cleaned by hand-labour does not affect the price, as might be expected, because the force required to detach a small amount of rust is also sufficient to remove a much greater amount. The variations in the cost are affected by different circumstances, as, for instance, by the distance between the site of the operations and the store where the working materials are kept, by accidents, and by want of uniformity in the thickness of the rusts and in the pressure of the water.

IV. Evil Effects of Corrosion.

The evil effects of corrosion are, first the loss of water-carrying space, and secondly, the loss of pressure.

Examples of the space occupied by rust, along with the ages of the pipes, will be found in Table III. This space is ascertained by filling the pipe with water, noting the quantity, deducting it from what the pipe should contain when clean, when the remainder gives the result required. The first four examples were taken where the circumstances attending the formation of rust were as nearly as possible the same, while the remainder were chosen at random.

Nos. 1 to 6 are of uncoated pipes; Nos. 7, 8, and 9 are of coated pipes.

Table III.

No.	Age of Pipe.	Internal Diameter of Pipe.	Amount of Rust per Lineal Yard.	Capacity of Clean Pipe per Lineal Yard.	Percentage of Space occupied by Rust.
	Years.	Inches.	Cubic Inches.	Cubic Inches.	
1	20	3	63·84	254·44	25·0
2	29	3	86·94	254·44	34·1
3	38	3	110·44	254·44	43·4
4	29	4	182·37	452·37	40·3
5	22	4	244·37	452·37	54·0
6	14	5	180·00	706·86	25·4
7	15	7	190·00 (about)	1,385·42	13·7
8	15	10	240·00	2,827·44	8·4
9	40	15	1,320·00	6,361·74	20·7

The rust has a marked effect on the discharge from a pipe; for instance, the water in a corroded pipe 3 inches in diameter, registered by the gauge a head of 77 feet, and through a 2-inch outlet (the same as that through which the pressure was measured) the discharge was only 16 gallons per minute; while after cleaning, the pipe registered a head of 82 feet, and a discharge of 150 gallons per minute.

The following Table gives additional examples; the results are the average gaugings of five different trials taken once a week on the same day. The theoretical head of water is in each case about 30 feet more than that registered by the pipes after cleaning:—

TABLE IV.—DISCHARGE from CORRODED PIPES.

No.	Size of Pipe.	Age of Pipe.	Approximate Amount of Corrosion per Lineal Yard.	Head before Cleaning.	Head after Cleaning.	Discharge per Minute before Cleaning.	Discharge per Minute after Cleaning.
	Inches.	Years.	Cubic Inches.	Feet.	Feet.	Gallons.	Gallons.
1	3	29	86·94	42	47	47	143
2	3	29	93·00	54	56	79	188
3	3	29	the same pipe	70	74	143	200
4	3	32	190·00	77	82	16	150
5	3	32	190·00	72	72	115	187
6	3	26	80·00	56	62	35	220
7	3	26	88·00	36	43	65	130
8	4	29	100·00	40	45	69	115
9	4	29	the same pipe	38	42	125	107

V. STRENGTH OF CORRODED PIPES.

It is difficult in the case of uncoated pipes to decide whether the strength of the pipe be affected more by the internal or by the external rust, as on inspection the inside of the pipe appears in a better condition than the outside when the rust has been removed.

The simplest mode of ascertaining the strength of corroded pipes was by finding their breaking weight. The pipes, selected with every possible care to avoid structural defects, were supported on a span of 4 feet, and force was applied in the centre till they broke. The same was done with a new pipe of similar size, thus obtaining a standard of comparison. The span of 4 feet was adopted, as it was difficult to get sound corroded pipes of greater length.

Table V. gives the results along with the calculated strength of the new pipe as found by the formula—

$$W = \frac{4\,K\,V}{L},$$ in which

W = Breaking weight in cwt.
K = Coefficient of rupture for cast iron.
L = Length of span.

$$V = 4\cdot 7\left(\frac{R^4 - r^4}{R}\right). \quad \begin{cases} R = \text{radius to outer surface, and} \\ r = \text{radius to internal surface of pipe.} \end{cases}$$

TABLE V.—STRENGTH of CORRODED PIPES.

No.	Age of Pipe.	Size of Pipe.	Thickness of Metal.	Length of Span.	Breaking Weight Formula, $W = \frac{4 K V}{L}$.	Actual Breaking Weight.	Actual Deflection at Centre of Span.
	Years.	Inches.	Inch.	Feet.	Tons.	Tons.	Inch.
1	new	3	$\frac{3}{8}$	4	3·51	4·07	about $\frac{3}{4}$
2	13	3	$\frac{3}{8}$	4	..	2·45	„ $\frac{3}{8}$
3	13	3	$\frac{3}{8}$	4	..	2·44	„ $\frac{3}{8}$
4	29	3	$\frac{3}{8}$	4	..	2·06	„ $\frac{1}{4}$
5	29	3	$\frac{3}{8}$	4	..	1·97	Hardly perceptible.

The external surface of pipes coated with asphalt remains in perfect condition for a considerably longer time than the internal surface.

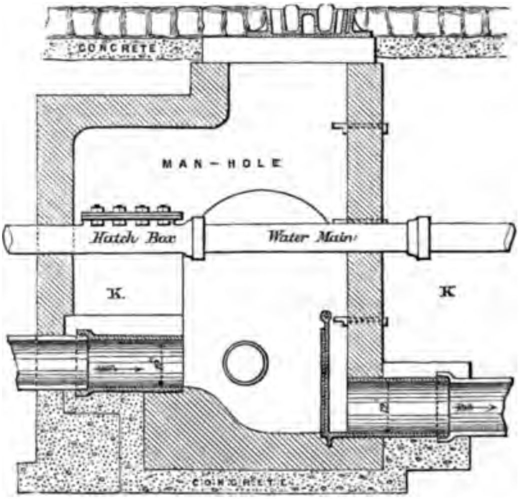
In conclusion, the Author is led to believe that the pipes of a town supplied with soft water, in which the rust has once been removed, may be kept in fair condition by their being cleaned once every five or six years, and at a cost considerably less than what is shown in Tables I. and II.; further that in the laying of pipes from 6 inches and upwards, hatch-boxes should be fixed, thus in the end saving considerable expenditure, besides affording ready means for future examination.

ADDENDUM.

Note.—Mr. ROBERT RAWLINSON, C.B., who presided at the Supplemental Meeting of Students when Mr. Jamieson's Paper was read, has requested that his opinion may be recorded as follows:—

This Paper is calculated to be instructive by reason of its giving clearly-expressed descriptions, with well-defined diagrams and details of the implements used, their mode of use, and tables of costs of the operations. One useful lesson these details may teach to young engineers is that, in new water-works, main-pipe cleaning should be contemplated and be provided for by a subdivision of the mains into areas and sections having hatch-boxes at suitable places. Each hatch-box should be in a manhole, having a movable cover at the street surface, and a bottom drain to remove water. Hatch-box covers may then be opened at any time without temporary damage to the street or road, and without injury to the mains, such as must be caused by cutting out a pipe or pipes. The facilities for cleansing by these means will be increased and the contingent costs much reduced.

FIG. 9.



Section of Manhole to facilitate pipe-cleansing by hatch-box.
Scale ¼ inch = 1 foot.

The evidence obtainable from this Paper is strongly in favour of a use of properly varnished pipes; and an engineer should stipulate in his specification that the pipes shall be treated with the material and in the mode described by Dr. Robert Angus Smith in his patent. The pipes should be cleaned and 'fettled,' and then at a temperature sufficient to expel some of the air from the skin of the pipe, and to dry the varnish quickly after dipping; the pipes and other castings should be dipped completely under, in a bath of the varnish, so as to coat the entire surfaces inside and outside of each pipe. With a use of proper varnish, and proper dipping and drying, each pipe, inside and outside, will then have a smooth black shining varnish skin. There is reason to believe that in many cases gas-tar alone is used, which may account for failures known to take place, as gas-tar does not combine and harden as the proper varnish will do, but washes off, causing a taint in the water which discredits the process.

(*Students' Paper No. 134.*)

"Caissons for Dock Entrances."[1]

By Daniel Macalister, Stud. Inst. C.E.

In this Paper some of the different types of caissons at present in use, and their external and internal arrangements, are described and illustrated by practical examples.

Caissons are constructed of timber and also of iron, and may be divided into three classes, viz., floating, sliding, and rolling caissons. Floating caissons are of two types; one of a rectangular or box form, fitting into a berth or recess in the dock entrance, and having meeting faces on its sides; and the other like a ship, having a keel and stem, with meeting faces secured to them, which fit into a groove in the dock entrance.

Iron Box Caissons (Plate 6, Figs. 1, 2 and 3).

Box Caissons are constructed of wrought-iron plating and angle-iron framing, stiffened by stringers, decks, and diagonal bracing. A little above the level of low water, a watertight deck divides the caisson into two compartments, the lower one being an air chamber of sufficient capacity, or displacement, to bring the caisson almost into a state of flotation when the water is at the level of the watertight deck, the upper compartment being for the purpose of floating the caisson when it is desired to open the dock. When the dock is closed, water is allowed to flow into the upper compartment through valves, to prevent the caisson from floating when the water in the dock is above the level of the watertight deck. To open the dock, the valves are closed before the tide rises to the level of the watertight deck, and as it rises above that level the caisson gradually floats out of its berth and is then hauled by tackle to one side of the dock entrance, out of the way of ships entering, or leaving, the dock. To close the dock again, the caisson is hauled into position across the entrance, the valves in the upper compartment are opened, and as the water flows in, the caisson gradually sinks into its berth and the dock is closed. To ensure regularity in sinking, the upper compartment is often divided by bulkheads into three divisions, with sluices to each, by regulating which, any tendency of one end to sink before the other may be counteracted. A sufficient quantity of ballast is placed in the bottom of the air chamber, to give the caisson stability during the operation of floating it into, or out of, its berth. The upper deck forms a roadway or bridge, to carry locomotive, or ordinary carriage and foot traffic across the dock.

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[1] This communication was read and discussed at a meeting of the Students on the 11th of March, 1881, and has been awarded a Miller Prize.

Timber box caissons are divided into compartments and worked in a similar manner to those constructed of iron, but they may be of almost any form; as an example, the caisson at the Regent graving dock, designed by Mr. W. R. Kinipple, M. Inst. C.E., is horizontally of a crescent shape, thus giving a greater length of floor of dock in the centre.

SHIP CAISSONS.

Ship caissons are constructed with wrought-iron keels and stems, angle- or T-iron frames, plated sides, and timber or iron decks, like an ordinary sailing ship.[1] The sides of the dock entrance and the stems of the caisson are battered to enable the caisson, when floating at the draught line, to clear the entrance. The caisson is floated out of and into its berth in the entrance like a box caisson.

Another form of caisson is that designed by Mr. David Cunningham, M. Inst. C.E., which might, however, be more correctly classed as a gate, because it is fastened at one end to the masonry of the dock entrance, and on being opened is swung round into a recess in the side wall in a similar manner to one leaf of an ordinary dock gate. It is constructed like a dock gate with the addition of a special pneumatic chamber or reservoir. When in position closing the dock, the caisson is suspended by projecting brackets secured to its ends, resting on corbels in the masonry of the entrance. To open the dock, air is pumped into the pneumatic reservoir, which causes the caisson to float off the corbels, and it is then swung round into the recess. To close the gate, the caisson is swung back into position across the entrance, the air is allowed to escape from the reservoir, and the caisson sinks until the brackets rest on the corbels.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lxiv., plate 7.

Sliding Caissons.

A sliding caisson is a box caisson, which, instead of being floated out of its berth on the dock being opened, is hauled endways into a recess in the side of the dock entrance. To do this, keels or rubbing-plates are fixed to the bottom of the caisson, which rest on sliding ways in the floor of the caisson berth and chamber, and when the hauling machinery is set in motion the caisson is hauled along the sliding ways into the chamber, leaving the dock entrance clear for the passage of ships, while the caisson is in a position of safety.

Rolling Caissons (Plate 7, Figs. 1, 2 and 3).

A rolling caisson is a box caisson, which is also drawn into a recess or chamber when the dock is opened. It is mounted on rollers which run on paths in the floor of the caisson berth and chamber (or the rollers may be placed on the floor and the keels on the caisson), and if it be desired to have a roadway over the caisson, the deck is mounted on levers which automatically lower as the caisson is drawn into the recess, to allow the platform to pass under the covering of the recess (Plate 8, Figs. 1 and 2).

The machinery for hauling the caisson into and out of the chamber may be a crab winch at the end of the chamber, and another on the opposite side of the entrance, with chains to each end of the caisson; or it may consist of an endless chain on each side of the chamber attached to a yoke and hauling bar projecting from the end of the caisson; the chains pass round a loose sheave on each side of the entrance to the chamber, and over two chain wheels keyed on to a shaft at the head of the chamber, which shaft may be worked by steam, hydraulic, or other power.

Iron Floating Box Caisson.

Figs. 1, 2 and 3, Plate 6, show the elevation, plan, and cross-section of the caisson at Messrs. R. and H. Green's new graving dock, Blackwall, designed by Messrs. Kinipple and Morris, MM. Inst. C.E. It is a box caisson 67 feet 3 inches in length, 10 feet in width, and 28 feet 9 inches in depth, having the outer corners rounded.

The caisson has one meeting face of teak-wood, which is protected from injury while the caisson is being shifted in and out of the berth by horizontal and vertical fenders projecting beyond the face. The outer plating of the caisson is of wrought-iron plates $\frac{7}{16}$ inch in thickness up to the watertight deck, and above that level $\frac{3}{8}$ inch and $\frac{5}{16}$ inch in thickness; the plating runs horizontally in alternate inside and outside strakes, lap-jointed and single-riveted; the vertical butt joints have cover plates, double-riveted. The plating of the bottom of the caisson is $\frac{1}{2}$ inch in thickness, and is stiffened by the vertical floor-plates $\frac{1}{2}$ inch in thickness, riveted to the side and bottom angle-irons. The spaces between these floor-plates are filled in with cast-iron kentledge and Portland cement concrete as ballast, to give stability to the caisson when floating. The angle-irons forming the side framing are 3 inches by 3 inches by $\frac{3}{8}$ inch, and placed 18 inches apart; the cross-beams of angle-iron up to the level of high water are 4 inches by 4 inches by $\frac{1}{2}$ inch, and above that level are 3 inches by 3 inches by $\frac{3}{8}$ inch, fastened with gussets to the side angle-irons; the uprights in the centre of the caisson are 4 inches by 4 inches by $\frac{3}{8}$ inch, and 18 inches apart; the angle-irons under the watertight deck are 5 inches by 3 inches by $\frac{3}{8}$ inch, widened at the ends and secured to the side frames; the deck beams are 3 inches by 3 inches by $\frac{3}{8}$ inch, secured by gussets. Horizontal plate stringers, 15 inches in width and $\frac{1}{2}$ inch in thickness, below the second tier from the top, and above that, $\frac{3}{8}$ inch and $\frac{1}{4}$ inch in thickness, are riveted to the cross-beams and secured by angle-irons to the outside plating and frames. The upper portion of the caisson is divided by watertight bulkheads into three compartments, each provided with regulating valves for admitting the water in order to sink the caisson into its berth in the dock entrance. At each end of the upper portion a watertight bulkhead forms a ventilator and manhole for access to the air chamber below the watertight deck. The bulkheads are of plating $\frac{3}{8}$ inch thick, stiffened with angle-irons riveted to the frames and beams, and secured to the watertight deck by angle-irons, thus forming efficient cross-bracing to the caisson. The meeting face of the caisson is of teak 14 inches in width by 7 inches in thickness, scarfed at the junctions, bedded in red lead, and bolted to 6-inch by 6-inch by $\frac{1}{2}$-inch angle-irons riveted to the caisson and following the curve of the masonry invert and the batter of the stop quoins. The seams between the angle-irons and teak face are caulked with oakum and pitch. The fenders are of rock elm 10 inches by 10 inches, secured by wrought-iron clips or brackets to the caisson. The planking of the roadway deck is of English oak 3 inches thick, secured to the deck beams and made watertight by caulking. Manholes are provided for access to the three upper compartments and the ventilators. Loop bolts are fixed to the corners of the caisson for attaching tackle for hauling it into and out of its berth. A 2-inch brass cock is fixed near the bottom of the inside face of the caisson to run off the bilge water into the graving dock, and a hand pump is provided to pump out any water in the event of the caisson springing a leak while out of its berth. The sinking valves are conical spindle valves of gun-metal, with spindles carried up to the roadway deck; the cast-iron inlet pipes pass by bends through the watertight deck, and are secured to the outside skin, the mouths being protected by brass rose heads. There are three sluices through the air chamber for filling the dock with water; the valves are 3 feet in diameter, of cast iron faced on both sides with gun-metal, and enclosed in cast-iron covers with gun-metal faces, and connected to the sides of the caisson by cast-iron pipes 3 feet in diameter, supported by the floor plates. The spindles are of gun-metal, passing up through the watertight deck in gun-metal stuffing boxes and continued up to the roadway deck by wrought-iron rods, worked by wheels and screws provided with indicators.

The dock was opened on the 16th of May, 1878, and the caisson has worked satisfactorily from the date of opening to the present time.

Iron Floating Caisson.

Figs. 4, 5 and 6, Plate 6, show the plan, elevation and cross section of the caisson at the Limekiln new graving dock, designed in 1864 by Mr. W. R. Kinipple. It is a box caisson of unusual form, being on plan like the two leaves of an ordinary dock gate, and is divided into an upper and a lower compartment by a watertight deck, these compartments being sub-divided by two watertight bulkheads. The outer plating is of wrought iron, the three lowest strakes being $\frac{1}{2}$ inch in thickness; the three above are $\frac{7}{16}$ inch, and the two top strakes $\frac{3}{8}$ inch in thickness, in alternate inside and outside strakes, with single-riveted lap joints and vertical butt joints with cover straps. The upper edge of the top strake is finished off with an angle-iron, to which is bolted a timber handrail. The plating of the bottom is 1 inch in thickness, and stiffened by the angle-irons forming the floor beams. The plating of the watertight deck is $\frac{7}{16}$ inch in thickness, having butt joints and cover straps, and connected to the skin plating and framing by angle-irons 3 inches by 3 inches by $\frac{3}{8}$ inch. The side frames are formed of similar angle-irons, spaced 2 feet apart, and divided into two pieces by the watertight deck. The angle-iron cross beams are also of the same size, secured to the side frames with lugs. The upright angle-irons in the centre of the caisson are 4 inches by 4 inches by ½ inch, riveted at the intersections to the longitudinal angle-irons and the cross beams. The horizontal stringers in the lower compartments are 15 inches in width and ½ inch in thickness, secured to the cross beams and skin; the stringers in the upper compartments are 12 inches in width and ⅜ inch in thickness, and are secured in the same manner. The two watertight bulkheads are formed of plating of the same thicknesses as the corresponding strakes of the skin plating, and stiffened by angle-irons, thus forming very efficient cross bracing. The roadway deck is of fir planking 3 inches in thickness, caulked and made watertight, and is 2 feet below the top of the caisson, the sides of which form the hand-rails. The meeting face of the caisson is of 6-inch by ¾-inch plate iron, and abuts against the timber meeting face of the dock. Ringbolts are fixed to the caisson for securing the tackle used in hauling the caisson into and out of the berth. The ends of the caisson are protected by fenders of teak, which abut against the skewbacks or abutments of the dock entrance. The caisson is provided with sinking valves, drainage cocks, and sluices similar to those previously described; and in addition there are two sluices, or mud ports, at the level of the dock sill for the escape of muddy water; each sluice is 18 inches by 9 inches, clear dimensions, formed of plate iron with a cast-iron flap valve on the outer end, worked by chains from the deck.

This caisson has been in use from 1865 to the present time.

SLIDING CAISSONS.

The Author understands that sliding caissons were first used at the Somerset dock, Malta, and afterwards at Portsmouth dockyard. Particulars of these have already been given.[1]

A good example of a sliding caisson also occurs at the Haulbowline navy yard, Cork.[2]

Three other examples of wrought-iron sliding caissons occur at the Milford docks for the lock and graving dock.[3]

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. xxxiii., p. 362; and vol. lxiv., p. 145.

[2] *Vide* Spon's "Dictionary of Engineering."

[3] *Vide* "Engineering," vol. xxxi., p. 81.

ROLLING CAISSONS.

Rolling caissons with horizontally bevelled ends have been introduced by Mr. W. R. Kinipple, and a Table is appended giving the principal dimensions of six caissons on this principle, either constructed or about to be constructed.

CERRO GRAVING DOCK CAISSON (Plate 7, Figs. 1, 2 and 3).

This caisson, designed for the Cerro graving dock, Monte Video, is a box caisson with keels attached to the bottom, which run on rollers placed on the floor of the caisson berth and the chamber in the side wall of the dock entrance. The caisson is similar in construction, internal fittings, and scantlings of framing and plating to the floating caisson at Blackwall graving dock previously described, with the exception that the ends are bevelled horizontally instead of being rounded.

The air chamber is of such capacity, and the caisson is so ballasted, as to bear on the keels with a pressure of about 5 tons when the tide is at the level of the watertight deck; and to keep this pressure uniform, adjusting valves are provided to allow the water to flow into the upper compartment as the tide rises above this deck. These valves are 8 inches in diameter, two on each side of the caisson, and of similar construction to those previously described. The keel rollers, set in the floor of the chamber, are of cast iron, with wrought-iron spindles lined with gun-metal, and working in gun-metal bearings in cast-iron frames. The rollers have flanges against which the spear ends of the keels press as the caisson is being drawn back into the chamber, thus causing the caisson to travel in the centre of the chamber, and so prevent abrasion of the timber meeting faces. Plate 7, Fig. 5, shows the form and dimensions of the keels, and the position of the rollers when the caisson is closing the dock entrance. The machinery for hauling the caisson into and out of the chamber consists of two endless chain cables, one on each side, attached to the ends of the yoke, which is fastened to the caisson by the hauling bar; these cables pass round loose sheaves at the entrance to the chamber, and over two chain-wheels keyed on to the driving shaft at the head of the chamber, the slack of the chains being carried by the chain rollers. The driving shaft is worked by a worm and spur wheel wrought off a capstan on the quay. Arrangements are made for keeping the caisson berth and chamber clear of mud, by placing the outlets of the filling and emptying culverts of the dock in the end walls of the berth and chamber. The chamber can be converted into a graving dock, for repairing and painting the caisson, by placing a temporary gate in a groove at the entrance to the chamber, and the water can be pumped out by a connection with the dock pumps. The caisson can also be floated out of its berth like an ordinary caisson, and placed against an outer meeting face, and so enable repairs and renewals of any work about the dock entrance and chamber to be effected without the aid of a cofferdam. When it is desired to do this the caisson is disconnected from the hauling machinery, the adjusting valves are closed at low water, and as the tide rises the caisson floats and is hauled back about 15 inches, so that one end clears the side of the dock entrance, and is then pulled round (Plate 7, Fig. 4) and sunk against the outer face in the position shown by dotted lines. The caisson has been constructed with bevelled instead of square ends, because with double-faced floating caissons of the ordinary types the side walls of dock entrances require to be built with a considerable batter, to enable the caisson to be floated in or out; and vessels entering, or leaving, a dock, with such an entrance, frequently have the paint or copper sheathing scraped off their bilges by rubbing against the sides of the entrance, under water. A case recently came under the notice of the Author, in which a large steamer had the grating over the injection pipe carried away as she was leaving a graving dock, by her bilge coming in contact with the battered side of the entrance under water. This accident would have been impossible in a dock entrance for a caisson with bevelled ends, as the side walls would be vertical.

ROLLING CAISSON AT GARVEL GRAVING DOCK, GREENOCK (Plate 8).

This caisson was designed in 1871 by Mr. W. R. Kinipple. It carries a counterbalanced lowering bridge for foot, carriage, and railway traffic. The caisson is somewhat similar in construction to that at the Cerro dock, previously described, with the exception that the rollers are attached to the caisson and run upon plate rails laid on the floor of the chamber and berth, instead of the rollers being laid on the floor, and the keels secured to the bottom of the caisson.

The lowering bridge is mounted on the caisson (Plate 8, Figs. 1 and 2), the roadway being at the same level as the quay when the caisson is in position closing the entrance. When the caisson is drawn into the chamber, the bridge and the handrails are lowered sufficiently to allow them to pass under the covering of the chamber. It will be seen from Plate 8, Figs. 1 and 2, that the bridge roadway is carried by a series of levers or parallel bars, the upper ends of which are fixed to axles working in plummer blocks, secured to the bottom flanges of the girders of the bridge, and the lower ends to axles fixed in a similar manner to the cross girders of the caisson. The outside bars are secured to the ends of the axles, and are continued for 4 feet above the roadway to serve as railing standards, the whole forming a parallel motion like a pair of ordinary parallel rulers. To counterbalance the weight of the bridge the ends of two pairs of levers are extended downwards, and boxes containing ballast are attached to these. Plate 8, Fig. 1 shows the bridge "up" when the caisson is in position across the entrance, and the part elevation shows the bridge " down " when the caisson is in the chamber. Plate 8, Fig. 2, is an enlarged part cross section when the bridge is "up." The raising or lowering of the bridge platform is effected by rollers fixed on each end, which work against curved plates in the abutment and the curved girder or lowering plate across the entrance to the recess. In hauling the caisson into the chamber, in order to open the dock, these rollers (one of which is shown in Fig. 1) abut against the convex "lowering plate," causing the platform and the handrails to fall down automatically into the position shown by the full lines at the end of the elevation. To close the dock, the caisson is driven across the entrance, and the rollers on the other end of the platform come against a concave "raising plate" fixed in the opposite side wall of the entrance, causing the bridge platform to rise up to the level of the quay. When the bridge is "up" it is so locked between the abutments that it cannot fall down until the caisson is drawn back. The machinery for working the caisson consists of an oscillating three-cylinder hydraulic engine, driving the shaft with chain wheels and chains (Plate 7, Figs. 1 and 2). With this caisson the dock can be opened or closed, by the engine man, at any state of the tide, in three minutes, at a cost of about 3*d.*

To make the caisson scour out the berth and chamber every time the dock is opened or closed, the ends are close-plated, so that there is no opening through the body, as in the caissons at the Somerset dock, Malta, and at the Haulbowline dock, Cork. Thus, when the caisson is drawn back into the chamber, the whole of the water displaced by the advancing caisson rushes under it and past its sides, carrying along with it any mud which may have been deposited in the chamber or berth. The caisson has now been working for seven years, and the chamber has been kept quite free of mud or deposit, so that there has been no occasion to use a sluice for scouring purposes.

This caisson was constructed in 1872 by Messrs. Hanna, Donald, and Wilson, of Paisley, N.B., at a cost of £7,797 complete, as follows:—

	£.
Cost of caisson	6,050
„ lowering bridge	1,450
„ hauling machinery	297
Total	7,797

The cost of a similar caisson at the present time would be much less, as the contract price of the plating was £34 per ton.

It is difficult but at the same time necessary to get a nearly perfect watertight joint between the meeting face of the caisson and the stone face of the entrance of a graving dock, because a few inches depth of water on the floor of the dock interferes to a serious extent with the comfort and convenience of the shipwrights and others engaged in repairing vessels, and involves a considerable expenditure for pumping. It may not be out of place here to describe shortly how a practically watertight joint was obtained at the first trial of the Garvel graving dock caisson without packing the joint with wedges, felt, leather, or india-rubber. The meeting faces of the caisson are of teak, and abut against the polished faces of the granite inverts and quoins of the dock entrance. In order to dress the faces of the granite quoins to a vertical plane, straightedges were erected, perfectly plumb, on each side and in the centre of the entrance. Fine wires were then stretched from one straightedge to the other, and offsets taken from the wires to the faces, by teak blocks 4 inches square, and the faces of the stone were fine axed and rubbed down until the offsets measured uniform distances from the wires to any part of the faces. After the faces of the inverts and stop quoins were dressed to vertical planes, they were finely polished with sandstone and emery, so as to present perfectly smooth surfaces to the teak faces of the caisson.

The teak faces of the caisson were dressed in a similar manner, straightedges being set up at the corners, and after the faces were dressed by hand planes, they were rubbed with sand-paper to remove any roughness.

ROLLING CAISSON FOR THE NEW GRAVING DOCK AT POINT LEVIS, QUEBEC.

This caisson is similar in construction to that shown in Plate 7, Figs. 1, 2, and 3, with the addition of the lowering bridge for foot and carriage traffic shown in Plate 8, Figs. 1 and 2, and was designed in 1878 by Messrs. Kinipple and Morris. Instead of the spindle valves for letting water into the upper compartment, it is provided with a pendulum valve which works automatically. It is also provided with stop valves, and in the event of an accident to the pendulum valve, the caisson may be worked by the outside valves in the ordinary manner. The pendulum valve is mounted on a frame, and can be raised out of its seat by a screw, so that it can easily be got at for repairs.

Messrs. Wigham Richardson and Co., Newcastle, constructed this caisson, and delivered it on board ship at Newcastle, for the sum of £5,700. The contract included fitting together and erecting in the contractors' yard, then taking down, packing, and delivering on board ship for Quebec.

A similar caisson was designed in 1877 for the Esquimalt graving dock, British Columbia, by Messrs. Kinipple and Morris, but it has not yet been constructed, the dock works not being sufficiently advanced for its reception.

ROLLING CAISSONS AT GARVEL WET DOCK, GREENOCK.

Two caissons for the entrances of this dock, now in course of construction, have been designed by Mr. W. R. Kinipple, and are to be finished this year. Each caisson differs slightly in internal construction from those previously described, the bridge being intended for frequent and heavy railway traffic. The cross girders, which carry the lower axles of the bridge levers, are so spaced as to be vertically over the centres of the keel rollers on which the caisson rests when the dock is closed, and wrought-iron columns extend from the bottom of the cross girders down to the bottom of the caisson, to transmit the weight of the dead and live loads of the bridge direct on to the rollers, to prevent the caisson being strained by the exceptionally heavy loads which will pass over the bridge.

Concluding Remarks.

The first cost of a floating caisson is no doubt less than that of a rolling caisson, because of the extra cost of the caisson chamber in the side of the dock entrance for the latter; but in numerous cases this is more than counterbalanced by the fact that the cost of working rolling caissons is only a fraction of the cost of working floating caissons. A rolling caisson can be hauled into or out of its berth by simple machinery, under the control of one man, at any state of the tide, and with a considerable breeze and current through the entrance. On the other hand a floating caisson can only be floated out at, or about, high water, when it frequently becomes quite unmanageable on a breezy day, or in a strong tide, requiring a large number of men to work it, and frequently it sustains damage by being driven against the quay. It is urged in favour of sliding caissons that they possess the advantage over rolling caissons of having no submerged rollers, which are liable to get out of order and difficult to get at. Rollers, however, possess the advantage of acting as guides to keep the rolling caisson in the centre of the berth and chamber while travelling, thus preventing abrasion of the meeting faces. Sliding caissons have no such guides, and if there is much clearance between the keels of the caisson and the sliding ways, there is a risk that the sliding caisson may jamb while travelling, as there is generally some current and frequently a strong breeze through a dock entrance, which, acting on the portion of the caisson, projecting beyond the chamber, while in motion, may cause one of the corners of the opposite end to come against the side of the caisson chamber. Possibly therefore the advantage rollers offer as guides may more than counterbalance any disadvantage they are said to possess.

The rolling caisson at the Garvel graving dock has now been in use since it was completed in January 1874, and there has never been any interruption to its working, although the rollers and paths have been submerged the whole time. From this it would appear that the objections commonly urged against submerged rollers and roller paths seem to be overstated, and further, if the rollers are placed in the floor of the chamber it is not a very difficult matter to remove them, or if they are placed on the bottom of the caisson they can be mounted in such a manner as to be easily removed.

A rolling caisson can be constructed with a lowering bridge to carry railway traffic across the dock entrance; and where it is necessary to retain water both inside and outside, as in a lock with double gates at its lower end, and to provide railway communication across, it possesses the advantages over double gates of shortening the length of the entrance, dispensing with a swing-bridge, and the cost of additional labour and machinery for working the gates and swing-bridge.

The contractors for the caisson for the new graving dock, Quebec, estimate the cost of a similar caisson, erected complete in a dock in the Thames, but with a lowering bridge for railway traffic, to be £8,000.

The width of the dock entrance is 62 feet, and as the overlap or width of the meeting face of the caisson is 1 foot on each side, the length of the caisson is 64 feet, and the depth is 31 feet 6 inches. A pair of dock gates having an overlap of 2 feet or a span of 66 feet, and having the ratio of rise to span 1 to 5, would be 71 feet in length, and 2,236 square feet in area. Mr. Harrison Hayter, M. Inst. C.E., estimates the cost of wrought-iron gates at from £1 10*s.* to £2 per foot super, when iron is about an average price.[1] The cost of gates of the above dimensions, at the average price of £1 15*s.* per foot super, would be £3,913, or very nearly half the cost of the caisson and folding bridge.

The Author believes that on comparing the cost of a lock fitted with a rolling caisson and folding bridge, with the cost of a lock with double gates and a swing-bridge, there will be, in the case of the former, a saving of about the cost of the swing-bridge. In the former, although there is the extra cost of the chamber, there is a considerable saving in the length of the entrance works over the latter, and these would probably counterbalance. The cost of two pairs of gates being about the cost of the caisson and folding bridge, the cost of the swing-bridge would be the excess of the latter, and to this must be added the cost of the machinery for working the dock gates and swing-bridge, together with the wages of men employed in addition to one man necessary to work the caisson.

The Paper is illustrated by several diagrams, from which Plates 6, 7, and 8 have been engraved.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lv., p. 72.

APPENDIX.

PARTICULARS of ROLLING CAISSONS.

Name of Dock.	Caisson.						Folding Bridge.		
	Length.	Breadth.	Depth from Roadway to Bottom of Caisson.	Depth from Top to Bottom of Caisson.	Width of Entrance.	Depth of Water on Sill of Dock.	Length.	Breadth.	Nature of Traffic.
	Feet. Ins.	Feet. Ins.	Feet. Ins.	Feet. Ins.	Feet. Ins.	Feet. Ins.	Feet. Ins.	Feet. Ins.	
Garvel graving dock, Greenock, N.B. Opened 1874.	59 6	15 11	28 0	25 6	60 6	20 0	60 5	12 10	Foot, cart and railway.
Cerro graving dock, Monte Video . Caisson constructed in 1876	61 0	9 6	30 9	29 0	54 6	24 0	..	..	Foot.
Esquimalt graving dock, British Columbia . . . . Dock works in progress.	71 2	15 10	34 9	33 3	65 0	26 6	72 3	10 6	Foot and cart.
Point Levis graving dock, Quebec . Dock works in progress; caisson constructed.	68 0	15 10	34 0	32 0	62 0	25 6	69 8	10 6	" "
Garvel wet dock, Greenock, N.B., caisson No. 1 . . . . Dock works in progress; caisson to be constructed this year.	74 0	15 10	41 0	38 6	70 0	32 0	77 9	13 0	Foot, cart and railway.
Garvel wet dock, Greenock, N.B., caisson No. 2 . . . . Dock works in progress; caisson to be constructed this year.	74 0	15 10	41 0	38 6	70 0	32 0	77 9	13 0	" "

(*Students' Paper, No. 140.*)

"Brick-and-Concrete, and Concrete Gasholder Tanks."[1]

By WILLIAM HENRY EDINGER, Stud. Inst. C.E.

IN "The Theory and Practice of Gas Lighting," by Mr. T. S. Peckston, published in 1819, a gasholder is described (page 220) "as composed of two distinct parts: that is to say, a capacious inner vessel, in large works generally made of sheet-iron, which is closed at the top and open at the bottom; and a cast-iron tank or wooden vat of about a foot or eighteen inches greater diameter for containing water." It is one of the earliest works upon gas lighting, and this extract affords an idea of the materials from which gasholder tanks were constructed in the early years of this important industry.

Wooden vats, such as are used by brewers, were little employed, but tanks of cast iron were extensively adopted for some years, being constructed of flanged plates bolted together, and caulked at the joints with iron cement; the tank was then encircled on its exterior by wrought-iron hoops, to help to resist the pressure of the water it contained. This type of tank is only now constructed where the site is of such an uncertain nature as not to admit of the use of any other material, especially in the presence of large quantities of water. Wrought-iron plates have been used in the construction of tanks, and stone has been employed where bricks could not be easily obtained, especially on the continent; but brick has been perhaps more extensively adopted than any other material up to within the last ten years.

Lime-mortar, hydraulic lime and Roman cement have been gradually superseded by Portland cement, which was employed, first in the foundations, and then in the joints and rendering of brick tanks, till finally, in 1871, Mr. G. T. Livesey, M. Inst. C.E., constructed a tank of Portland cement concrete, faced or lined with a thin brick wall, and known as a "composite" tank. The present Paper treats of this method of building and that which immediately followed it, of using concrete alone.

The nature of the site of course to some extent determines which of the two modes of construction is applicable. Trial borings are therefore usually made to ascertain the character of the subsoil, the London Clay, as it is impermeable to water, being no doubt the best for the purpose. The ordinary manner of commencing the construction of a tank is to excavate an annular trench to the depth of the foundations, and wider than the intended wall, the sides being shored.

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[1] This communication was read and discussed at a meeting of the Students on the 6th of May, 1881, and has been awarded a Miller Prize.

A trammel, or beam compass of wood or iron, of a length equal to the radius of the intended tank wall, and having a lead plumb weight suspended from its end at the required distance, is placed in the centre, so that a circle is ensured whilst building the wall. On its completion the earth in the interior of the tank is removed to form the dumpling, generally a truncated cone, this shape having the greatest strength, and is covered with a layer of some impervious material to prevent leakage.

Brick and concrete tanks have been occasionally constructed by building up an inner and an outer face of brickwork, the annular space being filled with concrete; but this method being costly was soon rejected, the inner facing only being retained, and the back of the wall is shaped by moulds.

In a tank designed by Mr. V. Wyatt, the constructing engineer to the Gas Light and Coke Company, and erected at the Redheugh Works of the Newcastle and Gateshead Gas Company, the internal diameter is 152 feet, and it is 31 feet 9 inches deep from the floor of the tank to the underside of the wall coping. The wall is formed of a facing of bricks 9 inches thick, laid English bond, and set in Portland cement mortar, the backing being of concrete composed of 7 parts of gravel to 1 part of Portland cement, measured dry, which was deposited in layers 9 inches thick, three layers only being executed each day. The top was then levelled off and grouted. The brick face is not bonded to this backing, the cohesive power of the cement in the concrete being greater than the strength of a brick, thus rendering it unnecessary. The wall has brick footings 8 feet 6½ inches long by 2 feet 6 inches deep, and, including the concrete backing, is 3 feet 4½ inches thick for the first 14 feet of its height, measured from the top of the footings, then 3 feet thick for 8 feet 6 inches, and 2 feet 8 inches to the lower side of the stone coping. The gasholder standards are supported by sixteen piers 29 feet 10¼ inches apart, from centre to centre, measuring from the inner side of the tank, formed of two 9-inch brick walls 4 feet 6 inches apart, and carried 8 feet back from the tank facing; the three-sided spaces thus formed were then filled with concrete, into which the holding-down plates and bolts were built. An advantage claimed for this cellular-like method of construction is, that the chances of unequal settlement of the concrete, and consequent fracture of the wall, are reduced. Hoop-iron bonds $\frac{1}{12}$ inch thick and 1½ inch wide are carried through the wall and piers; they are 4 feet 6 inches apart in the height of the wall, one strip being inserted in each half-brick thickness of its width, and they form a series of concentric bands, with extra strips intersecting them at the piers. Previous to being built in they were well tarred and sanded. These bonds have not been extensively adopted, it being sometimes considered that they would afford little support to a concrete wall, when the strains were sufficient to fracture the wall itself, that the insertion of such bonding is not in accordance with the homogeneous nature of concrete, and that there is no unity of expansion between it and iron; and that if used at all they would be better placed on the outside of the wall than built within it. The designer of this tank, on the other hand, contends that they strengthen it considerably, and that no fracture to which concrete walls are subject has occurred in any one of twenty tanks constructed by him, in which this bonding has been used.

The clay puddle employed was well worked, then passed through a steam pug mill, and afterwards thrown into position in 9-inch layers, being well punned and trodden up to the back of the wall; each layer was chopped into the preceding one.

Two stones were placed opposite each pier upon the floor of the tank, to receive the holder when down, and three were built into the wall-face above these landing stones 10 feet 6 inches apart in a vertical line, for the reception of the guide-bars. The whole of the wall has a stone coping, and a stone cap was placed upon the piers.

The inlet and outlet pipes, which are 30 inches in diameter, of wrought and cast iron, pass into a brick dry-well 11 feet in diameter inside, and 40 feet deep to the floor, which is 2 feet 3 inches thick, and has an invert formed within it. The space between the tank-wall and the well is filled with puddle. An arched chamber, leading from the tank to the lower portion of the well, is 9 feet wide, 5 feet high, and 14 feet 1½ inch long, from the inside of the well. The arch of this chamber is of four rings of brickwork, and the invert of three rings, the side walls being 3 feet thick. In a previously constructed tank of this type the arched chamber was carried right through from the well to the tank, the break being adopted as more conducive to watertightness, enabling the puddle to be well rammed down to the pipes; it also surrounds them in the chamber, a 4½-inch brick wall being built in its end to admit of the ramming of the puddle.

The cone commences 7 feet from the face of the wall, and has a slope of 2 to 1 for a distance of 40 feet, the summit being at the level of the original surface of the ground, which was 12 feet 6 inches below the top of the wall coping. The whole of the surface was coated with concrete to a thickness of 12 inches, and rendered on its surface with Portland cement. A circular brick pier, 17 feet 3 inches high, was placed on the centre to receive the gasholder framing.

In a brick and concrete tank, which has been constructed at the Beckton Works, but of a different type, the same engineer was influenced by the opinion that in an ordinary composite tank, such as the one just described, and the face of which is not rendered, the water in the tank, when filled, passes through the brickwork and concrete, and is arrested by the puddle backing, which receives the greater part of the hydraulic pressure, the service of the wall being to support the thrust of the earth whilst the vessel contains no water. The tank is 194 feet 8 inches in diameter, and 37 feet deep from the floor to the top of the coping, and is designed to meet these conditions, so that, contrary to the usual practice, the counterforts or piers are placed inside the tank with brick arches connecting them, and the front of the wall thus appears as a series of panels, whose inner faces have a batter against the earth of 1 in 20. Four courses of tiles in Portland cement mortar form the base of the wall foundations, upon which a bed of concrete 2 feet 6 inches thick is raised. At its base the wall is 4 feet 3 inches wide, and 2 feet 6 inches wide at the top, consisting of a 9-inch brick facing, and a concrete backing composed of 7 parts of gravel to 1 part of Portland cement. The standard piers are 6 feet wide, formed of brick on three sides, the space being filled with concrete. The secondary piers are of solid brickwork 2 feet 3 inches wide. They are vertical on the face of the tank, and being on its inside, the surface of the back of the wall is in one continuous sweep on plan, and is also vertical, so that there are no irregularities from projecting piers; the puddle can thus press uniformly, and there is less chance of its shifting its place. There is no dry well, but the inlet and outlet pipes are embedded in a solid block of concrete (as in Fig. 4, p. 356). The pipes are of wrought iron 48 inches in diameter, and in this case for convenience are placed on opposite sides of the tank. Their great width allows a man to descend them to effect repairs, or to remove a deposit of naphthaline. Some engineers prefer the dry well for all tanks, but the name is apt to be a misnomer, as frequently they are full of water, which has probably leaked in, at that point in the tank wall where the pipes pass through, the weakest portion of the structure. An estimated saving in cost of £2,000 in this case was effected by the abolition of the dry well. The cost of the tank at Beckton (where the puddle was 7*s.* per cubic yard) was £14 10*s.* per 1,000 cubic feet of tank capacity, the vessel being considered, for the purposes of calculation, flat on the bottom.

A rectangular brick and concrete tank, recently constructed at the same works, for holding ammoniacal liquor, tar, &c., is about 525 feet long, 60 feet wide, and 20 feet deep. As in this case it was important that the tank should be watertight, and Mr. Wyatt, the designer, was of opinion that concrete of the ordinary working proportions could not be made so, he adopted a somewhat different mode of construction. The wall consists of 9-inch brickwork for the facing and concrete backing, but between the two materials there is a grouting of Portland cement 4½ inches thick, which renders the tank completely watertight. In constructing such a wall, the concrete and brick are carried up simultaneously, a chase being preserved between the two by means of wooden filling. When the wall is raised to a height of 2 feet 6 inches, this filling is removed and the grout run in, occupying the chase and all interstices at the back of the brickwork, thus forming a complete bond between the brickwork and the concrete. Each layer is swept and watered previous to the next being run in. The grout is composed of 2 parts of silver sand to 1 part of Portland cement.

In addition to making the tank watertight, this grout gives great additional strength, as a 3-foot length, supported at both ends, will carry a weight twice as great as York paving treated in the same manner. The test for the cement is that adopted by the German cement users, *i.e.*, the cement selected is that which stands the greatest tensile strain, when mixed with 3 parts of sand, after having set twenty-eight days, one day in air and twenty-seven days in water. Hoop-iron bonding is used as in the previously-described tanks, excepting that it is not carried entirely through the concrete and brickwork, as it would otherwise interfere with the continuity of the grout. Upon the floor and dumpling the grout is floated on in three layers each 1½-inch thick.

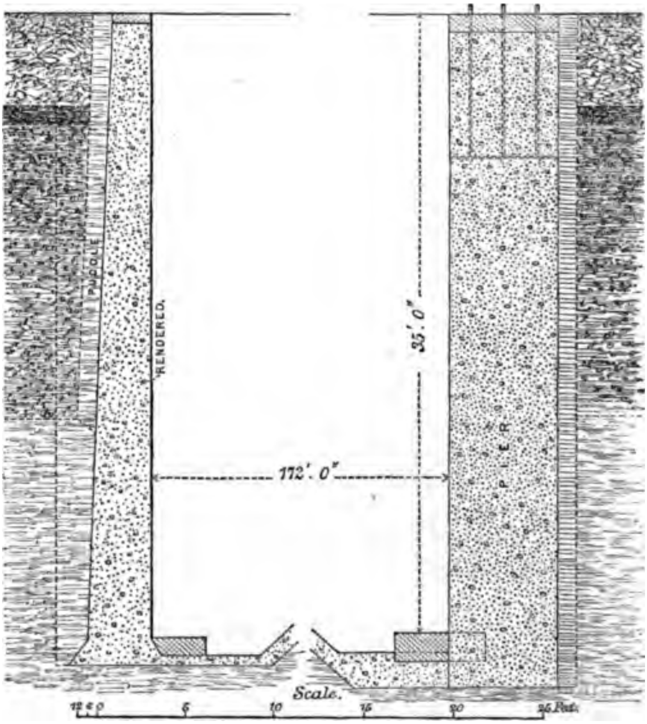
The liquor tank was ready for use in nine months' time from its commencement, whereas, had it been built in the ordinary manner with puddle, it would not have been ready for two years.

The first tank built entirely of concrete was constructed at the

South Metropolitan Gas Company's Works in the Old Kent Road, by Mr. Livesey, in 1875. Mr. John Douglas, Assoc. M. Inst. C.E., formerly of Portsea, about the same date constructed one of concrete, but with a brick lining, which was built up after the completion of the concrete wall, to ensure a circular face, as described by him, "the only effect of which was to gratify the eye."

The method of constructing these was similar to building ordinary concrete walls, *i.e.*, by the use of a framing of two moulds or shutters, of suitable length and width, placed vertically and parallel to each other, and at a distance apart equal to the width of the desired wall, being kept in their places by nutted bolts, thus forming the mould into which the concrete is placed.

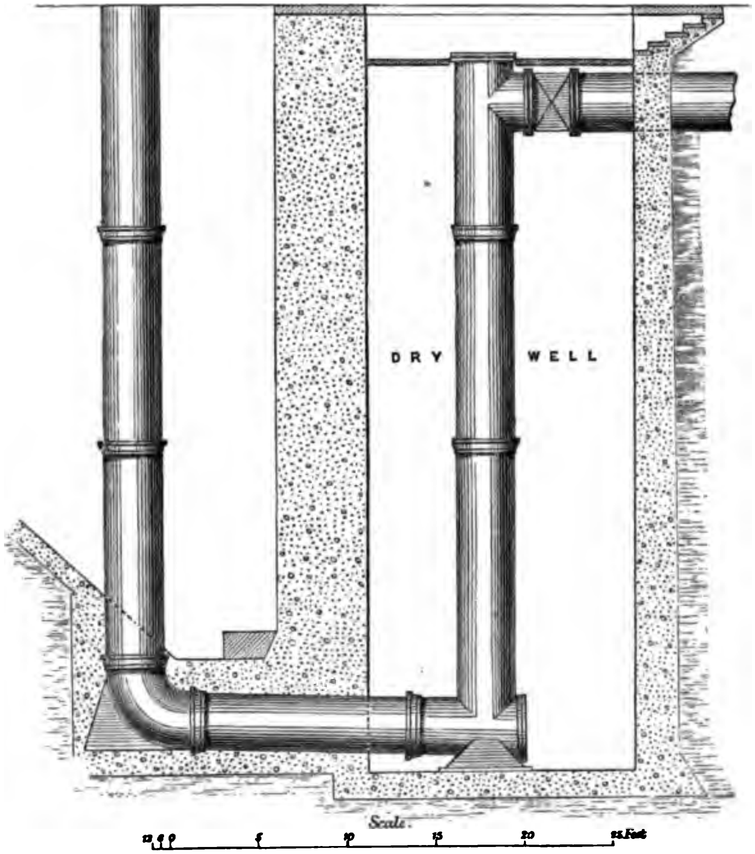
Fig. 1.



Sections of Walls of Concrete Tank.

A concrete tank constructed by Mr. Harry E. Jones, M. Inst. C.E., at the Poplar Works of the Commercial Gas Company, is illustrated in Figs. 1 and 2. These works are situated on marsh land on the banks of the River Lea. Measuring from the level of the marsh, trial borings showed 1 foot of soil, 3 feet of clay, 3 feet 6 inches of silty clay, and 10 feet of Thames ballast, below which was the London Clay. The ground having been marked out, a trench of an outside diameter of 186 feet and 7 feet wide was excavated for the wall,

FIG. 2.



Section at Dry Well.

and a further excavation was made for the dry well, both being securely timbered. Shutters for moulding the wall were made to the proper curve, were fixed in position, and the concrete dropped from a height between them. The wall is widened at its base, the width above this toe being 3 feet 6 inches tapering to 2 feet at the top. A backing of 12 inches of clay puddle was placed behind the wall, commencing from the top of the London Clay; the rest of the excavation was filled with clean clay. At nineteen equidistant points in the circumference the wall is widened outwards for the holder standards, and into these piers the holding-down bolts are built. The circular dry well is 15 feet in diameter and 43 feet deep, the wall separating it from the tank being 5 feet thick. The inlet and outlet pipes are of cast iron, 36 inches in diameter, and at the point where they pass from the well to the tank they are embedded in concrete, which at no point is less than 12 inches thick.

On the erection of the wall the earth in the centre was dug out to form a truncated cone, whose summit was 22 feet above the floor of the tank, and starting at a point 7 feet from the face of the wall its slope was at an angle of 45°. The annular floor space and the summit of the cone are coated with concrete 6 inches thick and the slope 12 inches thick.

The concrete used in the work was composed of 5 parts of clean washed ballast, 2 parts of sharp sand, and 1 part of Portland cement, excepting the upper part of the tank wall, 10 feet of which, measuring from the coping downwards, were formed of concrete having 1 part less ballast. The cement was required to stand a tensile strain of 330 lbs. per square inch, after having been moulded and set for seven days under water, and had to be delivered on the ground fourteen days before using, that it might be stored in a heap, so that any increase in bulk would take place then, and not after it was put into the work. The whole of the internal vertical face of the wall, 6 feet of the floor space, together with the outer side of the dry well, were rendered with Portland cement and washed sand in equal parts. Two stones were placed at the foot of each pier, and were bedded 2 feet into them.

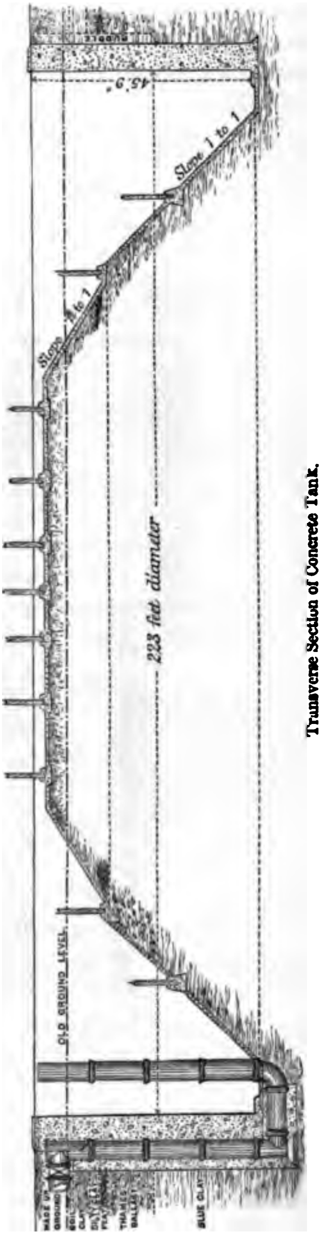
On filling this tank with water three cracks appeared, one about 12 feet long from the top of the wall, in that portion of it which was nearest to the Works' boundary wall, and where the excavation had shown faulty stratification; these cracks were afterwards stopped, and the tank is now perfectly sound. Its cost was £7,000, or £8 9*s*. per 1,000 cubic feet tank capacity; the concrete was about 12*s*. 6*d*. per cubic yard, including the cost of moulding. The gasholder has a capacity of 1,500,000 cubic feet.

Another concrete tank 223 feet in diameter and 45 feet 9 inches to the upper face of the landing blocks has just been completed at the same works from the designs of the same engineer (Figs. 3, 4, and 5). The wall was constructed in a somewhat different manner to that usually practised. Two concentric circles were marked out, and an annular trench 8 feet 3 inches wide was excavated, of an outside diameter of 239 feet 6 inches, and this trench was carried down to the London Clay at an average depth of 19 feet. The sides were timbered with runners set close (Figs. 4 and 5). Below this point the trench was narrowed to 6 feet 3 inches, which width was maintained to the bottom of the trench and was timbered by poling boards. On the top of the London Clay a garland was cut to collect the water draining from the upper strata, with a slope towards a point where a narrow cutting led to the sump. Water was met with about 5 feet below the surface of the ground, and was pumped out at an average rate of 7,000 gallons per hour.

Besides the trench, the earth was excavated to admit the inlet and outlet pipes for a length of 18 feet and a depth of 47 feet 6 inches from the level of the marsh. It was further excavated at twenty-two equidistant points in the circumference, where the wall was corbelled outwards to carry the holder standards, but this was not done until the concrete wall reached that point, where these projections commence. At the base the trench was bevelled outwards to form a toe.

No moulds or shutters being used in the trench to shape the wall, the faces of the runners and poling boards were set to a diameter of 223 feet by a plumb line attached to the trammel. Walings 14 feet long were used, placed in pairs, with three struts in each

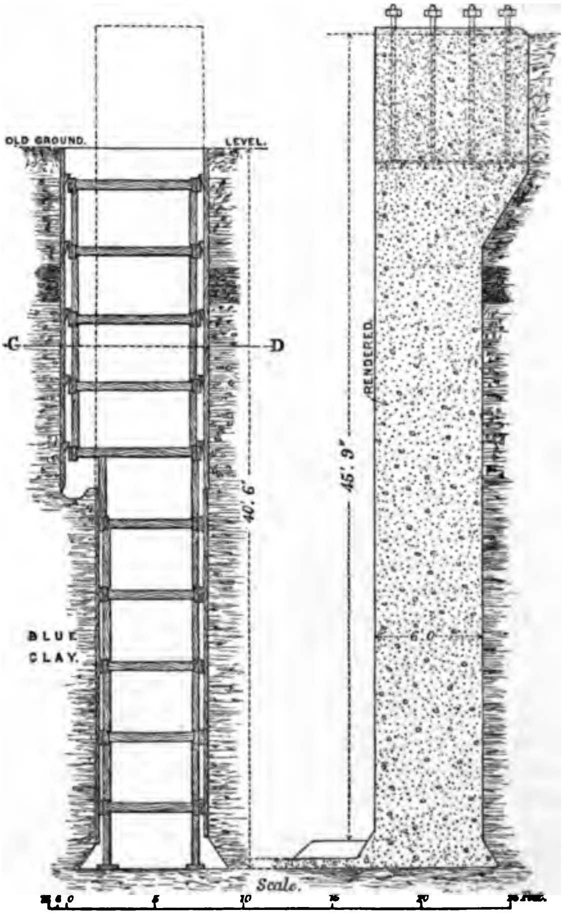
Fig. 3.



Transverse Section of Concrete Tank.

length, and were wedged against the runners in the upper portion of the trench to allow them to be lowered as the excavation proceeded. These frames were separated and supported by 3-feet puncheons, whose tops were nailed to the walings to prevent shifting.

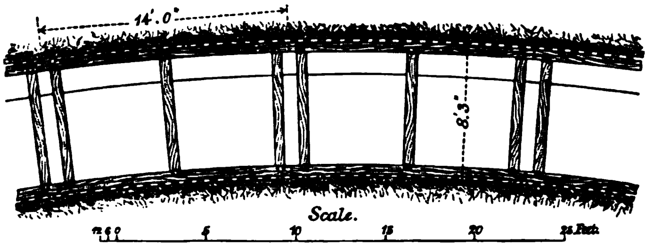
FIG. 4.


OLD GROUND.
LEVEL.
C
D
40' 6"
45' 9"
RENDERED.
BLUE CLAY.
6' 0"
Scale.
0
5
10
15
20
Feet.

Sections of Trench and Pier.

The concrete for the wall consisted of 1 part of Portland cement to 8 parts of ballast. The same quality of cement was required as in the previously-described tank, and the ballast was specified to contain at least $\frac{1}{3}$ part of its bulk of sharp sand. The materials were mixed upon a platform and turned twice dry, and three times after being moderately watered. The concrete was shot into place

FIG. 5.



Section of Timbering of Trench at C. D.

in layers 9 inches thick, not more than three layers being completed each day. When more than twenty-four hours intervened between depositing the layers, the last surface was swept and well watered before fresh material was added, which as this was done was levelled up to remix the constituent parts if separated by the fall from a height. As the wall was raised the timbering was removed, excepting those poling boards and runners which were against the inner face, these being left in position until the earth in the interior of the tank was taken out.

It was not specified that any clay puddle should be used, the tank face having to be rendered. The contractor for the work however did not think it possible to prevent the surface-water coming through the wall while it was being rendered, so at his own expense he placed puddle at the back to a thickness of 2 feet 3 inches, commencing above the London Clay, the trench being widened in its upper part for that purpose.

When the wall had reached that point where the piers project outwardly from it for a distance of 2 feet 6 inches, the concrete was moulded by shutters such as are mostly adopted, but which in this case were only used when the wall rose above the level of the ground. This mode of building possesses the advantage of economy, doing away with expensive shuttering which has to be made to the proper curve. It is not practicable in this way to obtain a true circle, especially one of such a great diameter, yet in this case the total error was nowhere more than 2 inches, *i.e.*, 1 inch in and 1 inch out, and as the guide-bars against which the holder works were fixed to the proper radius, this slight deviation was of very little importance.

Where the wall is moulded by shutters, it is necessary that the excavation of the trench should be several feet wider than the intended wall, this extra space having, after the erection of the wall, to be filled in with loose earth. This filling, however well rammed, can never be so secure as the original undisturbed soil, and therefore often recedes under pressure of the tank wall, which is thus in turn very liable to be fractured.

The pressure of water in a gasholder tank increasing as its depth, their walls are generally reduced from the base to the top, the upper portion thus having the greatest amount of loose backing. In the one now described, the whole of the lower portion of the trench being filled with concrete, is carried to the top of the wall of the same thickness, 6 feet, and so compensates in its upper part for the relative weakness of the backing where the ground is made up above the level of the marsh. The tank in process of construction at the South Metropolitan Works, when visited by the Students of the Institution in the summer of 1880, was in some respects built in this manner, the whole of the lower part of the trench having been filled with concrete. The wall having been completed, the earth in the interior of the tank was excavated to form the cone in the centre; this has a diameter at the base of 203 feet, and it slopes upwards at an angle of 45°, this portion being in the clay; above the clay there is a slope of 30° to the summit; the total vertical height is 44 feet above the floor of the tank. The floor and the whole of the dumpling were covered with concrete 6 inches thick, of the same quality as that used for the wall. Concrete blocks were built upon this dumpling to receive the ends of the timber framing upon which the crown of the holder rests.

The inlet and outlet pipes were of cast iron 48 inches in diameter, and were surrounded with concrete to the full extent of the excavation, and the dry well was thus abolished. Two concrete landing blocks composed of 4 parts of ballast and 1 part of Portland cement were placed on the floor of the tank opposite each pier. A coping was carried round the wall of moulded blocks made in the same way and worked to a smooth face with a composition of 2 parts of washed sand to 1 part of Portland cement; the upper angles of these blocks were rounded. The piers were also capped with blocks of the same description. The inside face of the wall and 3 feet of the floor space next to it were rendered with equal parts of washed sand and Portland cement, put on to a thickness of not less than ¾ inch and worked to a glazed, water-proof surface. This tank, which occupied twelve months in construction, has not yet been filled with water. Its cost was £15,000 or £8 3*s.* per 1,000 cubic feet of tank capacity, and the concrete cost about 10*s.* 6*d.* per cubic yard. The gasholder will contain 3,390,000 cubic feet, being one of the largest vessels of the kind.

Although the cost of some of the tanks described has been mentioned, the figures are of little value for comparison, as the price of concrete depends so largely upon the material at hand and the nature of the subsoil.

MEMOIRS OF DECEASED MEMBERS.

Mr. CHARLES BERNARD BAKER, second son of W. Baker, M.D., of Derby, was born in 1832, and was educated at the grammar schools of Derby and of Stamford. In 1850 he became a pupil of Mr. W. H. Barlow, V.P.R.S., Past-President Inst. C.E., and remained in the same office as an assistant until 1855. He then joined the staff of Messrs. Liddell and Gordon, by whom he was employed as an assistant on the Leicester and Hitchin extension of the Midland railway, and afterwards acted for one year as resident engineer on the Wimbledon and Epsom branch of the London and South-Western system, for Messrs. Locke and Errington, MM. Inst. C.E. In 1861 he rejoined Mr. Barlow's staff, the position then assigned to him being that of resident engineer of the Whitacre and Nuneaton railway; and afterwards one of the resident engineers on the London and Bedford, and on the Mansfield and Southwell lines, also belonging to the Midland Railway Company. Mr. Baker was engineer on his own behalf to the Mansfield waterworks, which were carried out under his direction. In 1874 Mr. Baker entered into partnership with Mr. Barlow and his son, Mr. Crawford Barlow, M. Inst. C.E., and so remained until his death, which occurred on the 10th of May, 1881, and during the partnership he rendered valuable and important aid in all the works the consideration of which devolved upon the firm. In addition to his professional knowledge and persevering industry, by integrity of character Mr. Baker commanded the respect of all who knew him.

Mr. JOSÉ MANUEL FARFAN DE LOS GODOS was born on the 1st of July, 1836, at St. Joseph, in the Island of Trinidad. He remained under the tuition of his father until the age of fourteen, when he was sent to Ushaw College, near Durham. In 1855, after spending five years at Ushaw, he entered, as a student of Dublin University, Dr. (now Cardinal) Newman's house, and in November of the same year passed his matriculation examination. In the following July he took a scholar's degree, and then left for Paris, there to study civil engineering. After passing his *Baccalauréat ès-Sciences*, and spending a year at the School of Mines, he entered the School of

Roads and Bridges in November, 1860. In April, 1862, he went to Spain, having, through the influence of the late Mr. John Bethell, Assoc. Inst. C.E. (brother to Lord Chancellor Westbury), been allowed to join, as a volunteer, the staff sent out by the contractors, Messrs. Oudney and Debrousse, for the construction of a railway from Valencia to Ponferrado, and acted for eight months as chief of a section of 14 miles. At the end of the year he left the service, owing to some difficulties between the chief engineer and his staff. He came to England in 1863, and on the 3rd of March was admitted an Associate of the Institution. A few days later he was appointed assistant engineer on the construction of the Granollero railway, in the Province of Barcelona, in Spain, where he remained for two years, and for six months was acting chief engineer. In April, 1865, he returned to England, and in October, 1866, he left for Trinidad. Soon after his arrival he entered the government service. The following were his chief appointments:—May, 1868, Assistant Commissioner of Crown Lands in the Ward of Montserrat; May, 1869, Warden of the Montserrat Ward; January, 1870, Warden of the Caroni Ward Union; 1876, Warden of the Arima Ward Union; 1877, Warden of the Tacarigua Ward Union. In 1878 he visited England, and was transferred to the class of Member of the Institution on the 29th of May, 1879, previous to his return. In 1880 he was attached to the Public Works Department (still retaining his post of Warden) for the purpose of surveying certain parts of the Colony, with a view to ascertaining precisely what new roads were required to be opened by the government. This sudden transition from the quiet and sedentary life of a Warden proved fatal to his already sinking health. He died from inaction of the kidneys on the 22nd of August, 1880, at his native city, where he was buried the same day.

From childhood he displayed remarkable aptitude for the exact studies, and so clearly was his taste for engineering manifested, that even when a boy no doubt was entertained as to his future career. Constitutionally slow to act, he sometimes, to all appearances, hesitated unduly before taking a decided step: however, those who knew him best were well aware that this did not proceed from sluggishness or indifference, but from an ever-present anxiety to give full weight to every point worthy of consideration, and the best proof that such was the case is to be found in the energy and perseverance with which he invariably acted when once his mind was made up. In social life it would be difficult to point to a man of more genial and lively disposition. His highest and most lasting encomium is to be found in the fact, that whilst conscientious and even severe in the discharge of official duties, he was in life beloved by all who were brought into contact with him, and now that he is dead no one has been found to speak a word against him.

MR. WILLIAM BANCKS HALL was born in Manchester on the 5th of June, 1829, and was educated at private schools in that city and at Altrincham. On the 25th of March, 1846, he began a term of five years' pupilage to Sir John (then Mr.) Hawkshaw, Past-President Inst. C.E., during which he was principally employed upon the heavy works of the Manchester and Leeds section of the present Lancashire and Yorkshire railway. On Mr Hawkshaw removing to London, Mr. Hall accompanied him, and remained until, in the autumn of 1852, he accepted an offer from Messrs. Fox, Henderson, and Co., to become engineer to their establishment in London. In this capacity he had to do with the various large contracts the firm had in hand, amongst others the Frankfort, Wiesbaden, and Cologne railway, of which line Mr. Hall had charge in Germany for two years during its construction. On returning to England he was appointed contractor's engineer on the East Kent (now forming part of the London, Chatham, and Dover) Railway, the works of which were begun under his superintendence. Later he took charge of the Contract Office of the London Works, Birmingham, until the suspension of Messrs. Fox, Henderson, and Co. in 1857. In the following year Mr. Hall went to South Africa as Resident Engineer to the Cape Eastern Province Railway Co., but, in consequence of difficulties which arose in the colony, the line was temporarily abandoned, and he returned to England. In 1859 he became engineer to Messrs. Trowsdale and Sons, and for them had the entire charge of the construction of the Cork and Kinsale Junction, and the Cork and Limerick Direct railways. On the completion of these lines, Mr. Hall was employed by the same firm to superintend the works of the Galashiels and Peebles railway, which he finished in 1867. From this time he was occupied for some months in negotiating for a partnership, which, however, was not brought about, and in July 1869 he was appointed by the Directors of the Lancashire and Yorkshire railway, assistant engineer, in which capacity he had general charge of the line, as deputy to Mr. Sturges Meek, the principal engineer of the company. During the ensuing seven years Mr. Hall was actively engaged in the important and responsible duties of the engineer's department of a great railway, besides superintending the construction of the Astley Bridge, Brighouse and Pickle Bridge, Clayton West, Heap Bridge, Hoddesden, Kearsley, Shawforth, and Stainland branches, as also the Manchester and the North Lancashire loop lines. In 1876 Mr. Hall left the Lancashire and Yorkshire company, and became associated with Mr. Barnes, the contractor for the Chatburn and Hellifield branch of the same system, but this proved a very temporary engagement owing to the contract changing hands. For two or three years prior to his death, Mr. Hall's pursuits were of a desultory nature, but in April 1881 he received an appointment on the Canadian Pacific railway. To this he looked forward with much hope, as a means of rehabilitating the somewhat shattered fortunes resulting from the unwisdom which too often accompanies high social qualities. A sad termination, however, awaited his long journey of 1750 miles from New York, for on the day after arriving at Winnipeg, in Manitoba, the head-quarters of the line, he was seized with dysentery, from which he died on the 18th of June, 1881.

Mr. Hall was elected an Associate of the Institution on the 3rd of February, 1857, and was transferred to the class of Member on the 4th of May, 1875. His death occasioned much sorrow to his old associates of the Lancashire and Yorkshire railway company, among whom he was a great favourite.

MR. JAMES SAMUEL STATTER, a son of the Rev. James Statter, Vicar of Wormenhall, near Oxford, and also a near relative of the celebrated Dr. Whewell, commenced his professional career in 1854, when he was articled for four years to Mr. Arthur Whitehead, M. Inst. C.E., County Surveyor of Somerset. On the completion of his pupilage, he first acted for a short time as Resident Engineer on works of sewerage and water-supply at Dorchester, and then became assistant to Mr. John Norton, architect, with whom he remained for two years to obtain that knowledge of architectural construction which he deemed necessary to qualify himself for general practice. At the early age of twenty-two he started on his own account, but his success was not sufficient to deter him from becoming a candidate for a Board of Health Surveyorship at Liverpool, which he failed to obtain, and after a year he joined the staff of Messrs. Peto, Brassey, and Betts, to superintend the erection of the stations on the Jutland railways, then under construction. In the palmy days of engineering, before the financial crash of 1866, many clergymen's sons entered the profession. The quiet and refined surroundings of a country parsonage found their converse in the life of adventure, often not unattended with danger, which awaited the young engineer when on foreign service, and in many cases presented an irresistible charm, almost as strong as that of going to sea. For this sort of existence Mr. Statter was eminently qualified, and his connection with Messrs. Peto afforded ample opportunity for gratifying his roving propensities. From the flats and swamps of Jutland he was, after a short interval spent in London, transferred to the Dunaberg-Witepsk railway, where he remained for a year and a half (1865–67), partly as assistant, and partly as district engineer, under Mr. W. Hartland, Messrs. Peto's agent in Russia. Another short interval at home on Parliamentary work, and Mr. Statter was found located among the plains of Eastern Hungary, training the half-wild peasants of the Lower Danube in the use of the navvy's spade. He remained on the East Hungarian railway for about two years, one of a large staff of English engineers under the orders of Mr. Charles Walker, agent for Messrs. Waring Brothers. But political and financial disputes hindered the completion of the railway, and the engineers being dispersed, Mr. Statter got an engagement on a trial survey for a line in Paraguay for the late Mr. C. B. Lane, M. Inst. C.E. After this arduous and most enervating work in a tropical climate, Mr. Statter returned to England, where he remained for about a year, part of the time being occupied as district engineer on the Somerset and Dorset railway extension to Bath. He next proceeded to South Africa, and arriving at Cape Town in September, 1874, was without delay engaged by the Colonial Goverment as an engineer on the Western system, under Mr. W. G. Brounger, M. Inst. C.E., the colonial railway engineer. He was first employed on the completion of the survey for the Worcester Extension railway, then in course of construction, and was afterwards appointed to the charge of a survey for a line to the town of Malmesbury, on a route selected by himself. This line was subsequently constructed. On the completion of the survey to Malmesbury, in April 1875, he was transferred to the construction department of the service, and was placed in charge of No. 2 District (a length of 26 miles) on the Beaufort West Extension railway, on which the works for several miles were of an important and heavy character; they were carried out departmentally, and were pushed forward with great rapidity and with complete success. Private affairs called Mr. Statter to England in June, 1877, when the Government relieved him from further duty, and granted him a substantial acknowledgment for the zeal and energy displayed in the discharge of the duties devolving upon him as District Engineer, having the superintendence of the heavy works of the Hee River Pass.

Mr. Statter returned to the Cape in November, 1877, and was then appointed to take charge of the construction of No. 7 District on the Beaufort West Extension railway, the district being nearly 27 miles in length, on which the works were also carried out departmentally. During the progress of these works he was detached in October, 1878, and had charge of an inspection of the country for a contemplated extension of several lines of railway in the direction of the Orange River, and was occupied on such duty until the month of May following. In November, 1879, on account of private affairs, he was obliged to leave for England, and to resign the service. The Government on this occasion again acknowledged the value of his services.

Mr. Statter returned to the Cape in May, 1880, after suffering in England from attacks of bronchitis, and not being under engagement he went on a visit to Beaufort West, where early in June his eyes were injured by an accident from a gun. He was in consequence under medical treatment until the month of September, when being convalescent, he was appointed by the Government as engineer in charge of a survey party to lay out a line of railway between Beaufort West and Kimberley, a length of about 300 miles. During the performance of this last-named service, Mr. Statter, who had complained for some time of not feeling well, left the survey party and proceeded for medical advice to Kimberley, where he died on the 26th of December, 1880, after being there about a fortnight.

Mr. Statter's energy was extraordinary, and the rapid promotion he received at the Cape was abundantly justified. His kindness of heart, his social gifts and straightforward conduct, drew around him a large number of friends, and those who were intimately associated with him have keenly felt the loss of a friend sincerely respected for his good and sterling qualities.

Mr. Statter was elected an Associate of the Institution on the 1st of April, 1873, and was transferred to the class of Member on the 13th of January, 1880.

Mr. RICHARD JAMES WARD, the eldest son of Mr. Francis William Ward, and grandson of Mr. Francis Ward, of the City of Bristol, Solicitor, was born in January 1817. On the death of his father, which occurred at the early age of 39, at St. Vincents, in the West Indies, where he resided as manager of the estates of his maternal uncle, Mr. Matthew Brickdale, formerly M.P. for Bristol, young Ward was taken to Scotland, where he was educated, and partly at the University of Aberdeen. In 1836 he was articled for four years to the late Mr. I. K. Brunel, V.P. Inst. C.E., during which period he was employed on the works of the Great Western railway at Paddington, and had charge of the construction of the bridges over the Thames at Basildon and at Moulsford, and of the erection of the locomotive engine shed at Swindon. At the expiration of his pupilage he was appointed resident engineer on the Oxford branch of the Great Western railway; and subsequently he occupied a similar position on the Wilts, Somerset, and Weymouth railway and its extensions, in all about 122 miles in length, from their commencement in 1844–45 to their completion in 1857. He was afterwards resident engineer on the East Somerset railway to Wells, and the Wells extension, 12 miles in length; and on the Berks and Hants Extension railway, Hungerford to Devises, 24½ miles in length, till the death of Mr. Brunel in 1859, when he became chief engineer for these latter railways, which were completed in 1863. Mr. Ward also constructed the Marlborough branch railway, 5 miles in length; the Wycombe and Oxford railway, 27 miles in length; and the Aylesbury branch railway, 7 miles in length, all of which were completed in 1864. In connection with Mr. John Fowler, Past-President Inst. C.E., he designed and carried out the Weymouth and Portland railway, about 5 miles in length; and jointly with Mr. J. W. Grover, M. Inst. C.E., in 1868, the Clevedon pier in the Bristol Channel, an account of which will be found in the Minutes of Proceedings, (vol. xxxii. p. 130). He was engineer for the Trowbridge (Wilts) Waterworks, and constructed the Waterworks at Shepton Mallet in 1859, at Wells and at Neath in 1862, and at Briton Ferry in 1866. He was appointed engineer to the Wilts and Gloucester railway in 1865-69, and to the Bridgewater railway in 1875, but these projects failed to command sufficient financial support. He constructed the Malmesbury branch of the Great Western railway system 5 miles in length, in 1877. He was, jointly with Mr. W. Purdon, M. Inst. C.E., and Mr. W. B. Lewis, M. Inst. C.E., in 1872, and afterwards with Mr. John Fowler, engineer for the construction of the Wexford and Rosslare railway, about 10 miles in length, and the Rosslare Harbour Works in Wexford South Bay; these works, in which he took great interest, believing they would tend towards alleviating the journey between the southern part of the sister kingdom, were in progress at the time of his death, which took place, after an illness of six months, on the 20th of May, 1881.

Mr. Ward was elected a Member of the Institution on the 7th of February, 1860. In carrying out the numerous works with which he was entrusted during his professional career, Mr. Ward was always remarkable for strict attention to the interests of his employers, to whom, as well as to a large circle of private friends and acquaintances, he was endeared by a character second to none for uprightness.

BARON CHRISTIAN PHILIPP MAX MARIA VON WEBER,[1] son of the celebrated composer, was born at Dresden in 1822. His mother was a lady of great culture, combined with depth of character, and she, assisted by the eminent naturalist, Lichstenstein—an old and faithful associate of his father's—conducted his early education, and exercised a beneficial and lasting influence over his mind. After having been thoroughly grounded in the classics, von Weber was sent to the Polytechnic School of Dresden, where he studied as an engineer. From thence he proceeded, in 1840, to Berlin, and entered Borsig's locomotive engine works to learn practical mechanical engineering. Notwithstanding his close application to the profession, he found time to attend lectures on political economy and natural science, by men like Dove and Magnus at the Berlin University.

In 1842, his apprenticeship served, he was employed in the construction of the Saxo-Bavaro-Rhenish and Saxo-Austrian railways, lines over extremely difficult ground, and comprising some noteworthy bridges and other important engineering structures. He commenced his career at the lowest step of the ladder, and is said to have held the post of locomotive engine driver for a year.

Subsequently he was appointed one of the leading engineers to the Chemnitz-Riese railway, but this post he does not seem to have filled for any considerable length of time; for in 1844 he was travelling over the continent and studying the various railway systems of Germany, Belgium, and France. He then came to England, and worked for a year under Stephenson and Brunel. When he returned from England in 1845 he was commissioned by the French Government to report on the condition of North Africa and its adaptability for emigration. The result of these investigations he embodied in two interesting works on Algeria and French Northern Africa. For his labours in the French service he was created a Knight of the Legion of Honour.

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[1] The substance of this memoir has been taken from "Zeitung des vereins deutscher Eisenbahnverwaltungen," 1881, No. 31.

On reaching Germany he undertook the management of the Erzgebirge railway; and he was called in 1850, as Technical Referee, into the Saxon Ministry for Public Works. In 1852 he was entrusted with the control of the Saxon State telegraphs. He had conferred on him the title of Financial Councillor (Finanzrath), and was made a Royal Saxon Director of State Railways and member of the Railway Board in 1853. On the change in the administration of the Saxon State railways, which took place in 1868, von Weber left the service and accepted an invitation from Vienna, where the post of Chief Consulting Engineer to the Austrian Ministry of Trade and Public Works was offered him, with the high rank of Imperial Aulic Councillor. Here he hoped there would be ample scope for his powers of organisation, as he had to rearrange the entire Austrian railway system under Count Beust, a task for the accomplishment of which he was peculiarly suited. But Count Beust's retirement, and the crash of 1873, which followed the short period of agricultural inflation, frustrated von Weber's plans. He was not happy in his official relations in Austria; his stern, North German, business ways, which formed a strong contrast to his really charming and amiable manner in private life, did not find favour with the polite and easy-going Viennese. During the notorious Ofenheim trial, in which he was called to give evidence as technical expert, he came into so open and sharp a conflict with his department, that he was obliged in 1875 to tender his resignation, at the close of the five years for which he had originally agreed to serve. While virtually at the head of railway affairs in Austria, he had contrived to give attention to the technical questions arising in other countries, and had travelled over the northern lines of Europe, and reported on the desirability of adopting the broad or narrow gauge in Norway and Sweden; and shortly before his resignation he had inspected the railways of European and Asiatic Turkey.

Finding himself now completely free from the shackles of office, his energies were devoted to engineering pursuits and literary activity. From his study at Vienna he directed and, to a certain extent, created continental railway literature. But he was not to enjoy his freedom long. The Minister of Commerce, Dr. Achenbach, asked him, in 1878, to give the German empire the benefit of his knowledge, in the capacity of Consulting Engineer to the Board of Trade at Berlin and editor of a ministerial railway journal. This scheme did not come to anything, owing to Achenbach's subsequent speedy resignation; but von Weber was attached extraordinarily to the German Board of Trade and Industry, and afterwards to the Ministry for Public Works, and was commissioned to make official journeys and to report on the canals and railways of Sweden, England, France, and North America. He could never reconcile himself to the State purchase of railways initiated by his own chief, a plan of which he was always a stout antagonist; and this made his position in Berlin a difficult one, and was the sore point of his latter days. He was never quite at home in the official atmosphere of Prussia, and so his labours assumed more and more a literary character.

On Easter Monday, the 18th of April, 1881, von Weber, having just finished his official report to the Minister for Public Works on the railways and canals of North America, died suddenly at Berlin of heart disease. He was only fifty-nine years of age and in the full possession of health and of intellectual vigour. His loss must be regarded as a calamity not only for railway men and civil engineers, but for the whole educated world, for he was truly a universal genius. He leaves a son and a daughter to mourn his loss; the former is a captain in the German army. His mortal remains were removed to Dresden, and he was there interred in the family vault beside his deceased wife and illustrious father.

Socially von Weber was one of the kindest and most agreeable of men. He had an inexhaustible fund of droll anecdotes, and there was hardly a subject on which he was not able to converse with ease, and to give information. At Vienna he lived in a circle of authors and artists of every description. His work over, he dropped the engineer and allowed his wide human sympathies full play. At the hotel of the "Ungarische Krone," he was in the habit of entertaining his friends once a week, and here his brilliant qualities as a host shone with a steady and unflickering brightness. But he did not bestow the inestimable gift of his friendship and society indiscriminately; he was cautious in confiding his views or expressing his real sentiments in the society of those whom he considered on an inferior grade of intellectual culture. The consequence was, that he was often misunderstood and frequently misrepresented. But this only afforded him additional amusement, and he enjoyed the hatred of his enemies as much as he valued the esteem and affection of his friends.

It has been lamented that von Weber was never placed at the head of railway affairs, and that he was always subordinate to a Minister. It has been thought that a special railway department should have been created for him, or that he should at all events have been made Minister for Public Works in Germany or in Austria. In either case he would certainly have had a larger sphere for his remarkable talents, and been enabled to leave a more lasting impression of his usefulness on continental railway systems. As it is von Weber has made a name that time will not speedily efface. Engineering science found in him a popular apostle, who was able to convey to the outside public, in attractive and elegant language, the important truths and facts connected with the profession. He lifted railway travelling from the domain of dull prose and surrounded it with a halo of romance. His railway novels stand forth unique among the literature of the century. He has also added no small contribution to that most interesting and valuable branch of literature, to which the historian is so much indebted for his facts, and young men for their ideals, namely, biography. His biography of his father is not only a worthy tribute of an affectionate son to parental genius, but shows an artistic insight, and a knowledge of music that testifies to his versatility.

Von Weber was elected a Member of The Institution of Civil Engineers on the 14th of January, 1873. He was a member of many of the leading learned and scientific societies of Europe and of America, Doctor of Philosophy of the University of Leipzig, Imperial Royal Aulic Councillor of the Austrian Empire, Commander of the Royal Swedish Order of Wasa, first class with the star, Commander of the Imperial Russian Order of St. Anne, Knight of the Legion of Honour of France, and knight of numerous orders of nearly all civilized countries, and possessor of several gold medals presented him by foreign governments. His principal work is "Die Schule des Eisenbahnwesens;" but he has written so much, and his activity has manifested itself in so many branches of contemporary literature, that it is beyond the limits of this memoir to give a detailed account of all of them.

Mr. JOSEPH FRANCIS DELANY was born in Rotherhithe in 1833, and was educated at Prior Park College, Bath. He served an apprenticeship as a mechanical engineer to Messrs. Joyce and Co. of Greenwich, and was for about two years with the same firm as naval architect and manager of the iron ship-building department. In 1861 he started the Victoria foundry and marine-engine works at Greenwich, in conjunction with Mr. J. C. R. Okes, Assoc. M. Inst. C.E. Mr. Delany was an accomplished naval architect, and built several very successful vessels, amongst them the steam-yacht "Wolverene," for Lieut.-Col. Brandram. The great depression of trade which ensued on the commercial crisis of 1866 induced the proprietors of the Victoria foundry to close the works. On the severance of this connection Mr. Delany, who had by his marriage with the daughter of Mr. Dixon, late chief cashier of the Bank of England, obtained interest in financial circles, became manager of the Greenwich branch of the North Kent Bank. Here he remained for several years; but the sedentary nature of the occupation was not suited to his tastes, and, on the death of his wife and infant daughter, he sought to dispel the gloom of the bereavement in an entire change of life. In 1874 he became chief engineer of the Chilian iron-clad "Magellarw," and was subsequently promoted to be chief constructor of the Chilian navy. He died at Valparaiso, in 1881, of consumption; his two sons having shortly previous fallen victims to the same complaint.

Mr. Delany was elected an Associate of the Institution on the 7th of March, 1865; and, on the reconstitution of that class in 1878, was made an Associate Member.

Mr. WILLIAM HUMBER, the author of several well-known works on engineering subjects, including "Cast and Wrought-Iron Bridges," the "Record of Modern Engineering," and "Water Supply," was born in 1821. His professional career was commenced in 1835, as a pupil to Mr. G. Watson, who superintended Mr. Hugh M'Intosh's contracts on the Great Western railway, then in course of construction. After the completion of a four-years' pupilage he was employed by various contractors until 1847, when he became one of the staff of the late Mr. Thomas Brassey, with whom he remained for five years. In 1852 he commenced practice on his own account, and was engaged in surveying lines of railway, in projecting water and drainage works for several towns and for urban sanitary districts, and in the construction of works. Between the years 1862 and 1868 he designed and carried out wrought-iron roofs for the Cremorne music-hall and theatre; wrought-iron roofs and galleries carried on cast-iron columns, for extensive farm buildings at Eastwood, Harptree, Somersetshire, for Mr. William Taylor; and was engineer to the Trowbridge Water Supply Company. The Bridport Waterworks, for which an Act was obtained in 1872, were carried out under his superintendence, during the years 1872 to 1874 inclusive. He likewise projected the Topsham Limpstone and Woodbury waterworks, at Woodbury, combining a storage reservoir (of a capacity of twenty million gallons) with bywashes and appendages, but the works remained in abeyance for want of the necessary funds. In 1874 he laid down a system of drainage and sewage utilisation for the local board of the Manor of Aston (juxta Birmingham), and prepared the necessary plans and estimate for an application to the Local Government Board for sanction to borrow £80,000 for carrying out the works. In August 1874 Major Hector Tulloch, R.E., Assoc. Inst. C.E., held an inquiry, and recommended that a loan of £80,000 should be granted. In 1875 Mr. Humber prepared the necessary contract drawings for two intercepting sewers, and a portion of the outfall sewer, and some other works, forming a section of the aforesaid work, when Major Tulloch recommended that a first instalment of £30,000 be granted for carrying out this part of the project. At this stage the urban sanitary authorities of Handsworth applied to the Manor of Aston local board to consider the advisability of constructing the above-named intercepting and outfall sewers of sufficient capacity to carry the sewage of their district, instead of each board having independent sewers. Mr. Humber was consulted on the subject, and he prepared fresh contract drawings and estimates, which were submitted to the Local Government Board. On the 15th of May, 1876, a second inquiry was held, and the project was sanctioned, the Handsworth authorities being empowered to borrow £15,000 as their contribution for carrying out the first portion of the combined intercepting and outfall sewers. In 1876 Mr. Humber was instructed by the Handsworth urban sanitary authorities to lay down a complete system of drainage for their district, comprising over 3,600 acres, and prepared the necessary plans and estimate for the purpose of applying for a loan. He was employed in 1875 to report as to a system of drainage and sewage utilisation for the local board for the district of Balsall Heath, in the county of Worcester, and subsequently to prepare preliminary estimates for the same.

Three or four years before his death Mr. Humber fractured his knee-cap, and he never quite recovered from the effects of the accident. He died suddenly, from an apoplectic seizure, on the 14th of April, 1881. His connection with the Institution dated from his election as an Associate on the 6th of May, 1856.

MR. LAUCHLAN ALEXANDER ENTWISTLE MACKINNON was born at Foxholes Hall, Rochdale, on the 3rd of June, 1843, and was educated at the Royal Naval School at New Cross. On leaving school he served an apprenticeship of two years to Mr. James Simpson, Past-President Inst. C.E., at the Grosvenor Engine Works, Pimlico, and subsequently acted as secretary during the building of the Furness Iron Company's works at Askam-in-Furness; and was also employed to take levels, both above and below ground, at the same mines, in succession to Mr. C. J. Clarke, Assoc. M. Inst. C.E. After some years passed in commercial pursuits, Mr. Mackinnon resumed the practice of the profession in 1873, entering the service of the Leeward Islands' Government as Superintendent of Roads, Bridges, and Public Works in Antigua. In 1878 he was removed to St. Kitts and Nevis, and he died on the 27th of February, 1881. Mr. Mackinnon was a man of an original turn of mind, and was constantly scheming new means of employing local resources in public works. He got great credit for the erection of a pile lighthouse at Sandy Island, Antigua, which has successfully withstood the furious hurricanes to which the spot is liable, and which had previously swept away two similar structures. A description of this work will be found in the Minutes of Proceedings, vol. lxiii., p. 255. He was also, at the time of his death, trying to induce the planters to make tramways on their estates, on an ingenious principle initiated by himself, for conveying the sugar-canes from the fields to the crushing mills.

Mr. Mackinnon was elected an Associate Member of the Institution on the 1st of April, 1879.

MR. GEORGE BROOKE MURIEL was the only surviving son of Mr. Brooke Muriel, of Sydenham, surgeon. He was educated at King's College, and in 1859 was articled to the late Mr. Christie, of King William Street and Bankside. On the completion of his term with Mr. Christie, he spent a few months at the works of the

Horseley Company, Tipton, Staffordshire. Returning to London, Mr. Muriel superintended the building of a house at Chislehurst for Mr. Christie, and afterwards visited the principal cities on the Continent, remaining some months in Spain and Portugal, and acquiring a knowledge of the Spanish and Portuguese languages. In 1868 Mr. Muriel was clerk of works at the Southall gasworks. While there his intelligence and acquirements bringing him into notice, he was, although only twenty-seven years of age, appointed engineer and manager of the Ottoman Gas Company. He remained at Smyrna five years, resigning his appointment in 1874, in order to attend to urgent private affairs. After a short stay in England, Mr. Muriel accepted the post of engineer to the Bahia Gas Company, which up to that period had been unfortunate, and was (at the time Mr. Muriel went to Bahia) paying no dividend. Under Mr. Muriel's judicious management the shares of the Bahia Gas Company nearly doubled in value, and at the time of his death the Company was paying a dividend of 7½ per cent. per annum. He was about to return home on leave of absence when he was attacked by the most virulent form of yellow fever, to which he succumbed, after three days' illness, on the 9th of April, 1881, aged thirty-nine.

Mr. Muriel's distinguishing characteristics were indomitable perseverance, great power of organisation, tenacity of purpose, and open-handed generosity. He was elected an Associate of the Institution on the 4th of May, 1872, and was also connected with several other societies, besides being a member of the Britannia Lodge of Freemasons (No. 33).

MR. JAMES JENKIN TRATHAN was born in Falmouth on the 7th of February, 1822, his parents being members of the Society of Friends. After the death of his father, who was a printer, the business was carried on by his mother, and her son, when his schooling was finished, assisted her. James Trathan was educated at a Quaker's school kept by a very intelligent man, Mr. Lovell Squire, who has long had charge of the Meteorological Observatory at Falmouth. The Cornwall Polytechnic Society was established at Falmouth by the well-known Quaker family, the Fox's. After a few years of struggling infancy, the institution obtained royal patronage, and Mr. Thomas Jordan—a man of unusual inventive powers—was appointed secretary, and the printing of the annual reports was entrusted to Mrs. Trathan. James Trathan was thus thrown into immediate contact with the clever secretary, and with the high-class mining engineers, who became the judges of the various mechanical inventions which were annually submitted in competition for the prizes and premiums offered by the Society. This awakened in him the natural mechanical genius which the young man possessed. In 1840, Mr. Jordan being appointed the Keeper of Mining Records in the Museum of Practical Geology, Mr. Robert Hunt, F.R.S., became his successor, and James Trathan afforded him valuable aid, from the knowledge which he had obtained during the seven years he had been actively, though indirectly, connected with the Cornwall Polytechnic Society. A close intimacy was formed between Mr. Hunt and young Trathan, who always took great delight in the photographic and physical experiments which Mr. Hunt was then pursuing. A disastrous fire and a series of misfortunes compelled Mrs. Trathan to resign her business, and James Trathan sought employment amongst the engineers. He visited his old friend Mr. Jordan in London, but was not successful in meeting with an engagement. Then, through the influence of Mr. S. W. Jenkin, M. Inst. C.E., he obtained a situation on the works of the Liskeard and Caradon railway, at that time in course of construction; and acted as assistant engineer and superintendent of rolling stock. After the completion and opening of the line he was for many years traffic manager, indeed his connection with this line continued to within about twelve months of his death. In the year 1855 he became a member of the firm of Jenkin and Trathan, Civil Engineers, Liskeard, and in 1867 of the firm of Jenkin, Trathan, and Truscott, and was engaged on various works in connection with:—The East Cornwall Gunpowder Company, the Liskeard and Looe Union Canal Company, the construction of harbour works at Looe and Polperro, the Liskeard waterworks, the Lostwithiel and Fowey railway, the Newquay and Cornwall Junction railway, the Looe water and gasworks, the Bodmin waterworks, waterworks for the Cornwall County Lunatic Asylum, the Camborne waterworks, the Topsham waterworks, the Dorking waterworks, the Plymouth, Stonehouse, and Devonport tramways, Ivybridge drainage and waterworks, the Cornwall Minerals railway and other railways connected with that Company, and various other works of lesser magnitude. He was also for many years manager of the well-known Cheesewring granite quarries. During the last few years of his life he was obliged, by the state of his health, to retire in a great measure from active work. He died at Teignmouth on the 8th of June, 1880, in his fifty-seventh year. Mr. Trathan was elected an Associate of the Institution on the 1st of December, 1857.

MR. JOHN DAVID BARRY was born at Chester on the 4th of February, 1832. He was the only son of John David Barry, well known to many of the older Members of the Institution in connection with the establishment of some of the earliest trunk lines of railway in France, and notably as the most active founder, and subsequently Director, until his death in 1874, of the Orleans and Bordeaux line, the construction of which, under English control, was in a great measure due to the persistence and energy which the elder Mr. Barry displayed in calling the attention of English bankers and railway contractors to the importance of the French General Law of Railways of 1842.

After serving his pupilage for two years at Glasgow under the late Mr. R. Napier, M. Inst. C.E., Mr. Barry was engaged for some time on railway surveys in France, and also acted for two years as assistant-engineer under Mr. G. Woodhouse, engineer for the construction of Le Mans railway. In the spring of 1855 he went to Scinde, as first-class assistant-engineer on the Scinde, Punjaub and Delhi railway, where he remained for three years. Whilst at Kurrachee, during the hot season of 1857, the mutiny broke out. Sir Bartle Frere and General Scott were temporarily absent at Clifton (5 or 6 miles from Kurrachee), leaving in command Brigadier Louth, with only two companies of Europeans and a small force of artillery. The 14th and 21st Native Regiments had made all their preparations to mutiny at midnight and murder their officers, when, an hour before the appointed time, a Havildar with some difficulty succeeded in bringing their plans to the notice of the brigadier, who immediately proceeded to surround and disarm them. But, owing to the small number of European troops, this was incompletely effected, and some of the Sepoys, under cover of the darkness, succeeded in escaping with their arms, so that it became necessary for a time to patrol the camp at night. This work was entrusted to volunteers, under the command of Captain Johnson, and of these volunteers Mr. Barry was one of the most active and efficient. Twenty-seven of the fugitives were tracked and captured.

Returning to Europe in 1858, Mr. Barry was engaged for the next few years on railway surveys in Italy and in Germany, and was appointed chief of a considerable staff of engineers, with whose assistance he laid out the German portions of the railway connections which now form what is popularly known as the direct line from Paris to Hamburg and Bremen. In 1865 he proceeded to Spain, and during the succeeding five or six years resided at Barcelona, where he held the post of Chief Engineer to some Catalonian companies formed for the construction of the important irrigation canals known as the "Tamarite" and "Cinco Villas" in Aragon, as well as that of Chief Engineer to the San Juan de las Abadesas railway company in Catalonia, and subsequently to the "Principe Alfonso" company, which undertook the construction of a canal for the irrigation of some extensive districts in New Castile. He returned from Spain to Paris in 1871, interesting himself in matters connected with applications of electricity to lighting purposes and as a motive power, and had much to do with the first introduction of the Gramme dynamo-electric machine into England.

In 1875 Mr. Barry went to California, where he was engaged until three months before his death in conducting the working of gold quartz and gravel mines, for the successful management of which he made himself a great reputation. Several of his reports on Californian gold mines have been printed as pamphlets, and of these he presented three to the library of the Institution. On the fever for Indian gold mines breaking out in the early part of the present year, he came to England in the expectation of drawing the attention of enterprising speculators in such mines to the superior and more solid claims of Californian reefs and gravel beds, but when apparently on the eve of a great success, an acute attack of heart disease occasioned his sudden death on the night of the 23rd of June, 1881.

Mr. Barry enjoyed the respect and esteem of all who knew him, and his tact and kindness to all about him, together with a peculiar charm of manner, had gained him the affection of a large circle of friends at home and abroad. He was elected an Associate of the Institution on the 7th of December, 1858, and occasionally attended the meetings. During the discussion on "Irrigation," in the session of 1867-68, he addressed some interesting remarks on the subject of "Irrigation in Spain" to the meeting, and he also contributed, through the Secretary, some observations on the "Mechanical Production of Cold," which are printed in vol. xxxvii. of the Minutes of Proceedings.

SECT. III.

ABSTRACTS OF PAPERS IN FOREIGN TRANSACTIONS AND PERIODICALS.

The Influence of Wöhler's Experiments on the Design of Structures in Iron, especially of Iron Bridges. By Prof. MOHR, of Dresden.

(Der Civilingenieur, 1881, col. 1.)

The Author considers it remarkable that immediately on the result of Wöhler's experiments becoming known there should have been an outcry for a modified system of design, and for fresh regulations on the construction, of works in iron. He holds Wöhler's so-called "law" to be, in its numerical application, of limited validity and of doubtful accuracy; and that the necessity for giving up the old system of maximum limiting stresses, which was founded on extensive experience, cannot be held to be demonstrated.

If Wöhler's law be accepted as the basis of an empirical formula, a variety of factors would have to be introduced in addition, of which the following are only the principal:—

1. The magnitude, form, and composition of the cross section.
2. The strength of the joints.
3. The duration of the load.
4. Shocks due to a moving load.
5. It must be recognised that the safety of a compound structure, such as a girder, is not directly proportional to the strength of the separate members.
6. Inaccuracy in computing the stresses, which in some members can be calculated with great accuracy, in others not within an error of from 30 to 50 per cent., or even more, would have to be guarded against.

When these various influences are borne in mind, the Author considers that a less appropriate field for the application of an empirical formula could scarcely be found.

Taking the average of formulæ proposed by Gerber, Launhardt, Müller, Weyrauch, Schäffer, and Winkler, the following mean values for permissible stresses in railway bridges are obtainable: n being in each case the ratio of the numerically least to the greatest of the alternating stresses to which any piece is subject; i. e. $n = -1$ if the stresses vary between tension and compression of equal magnitude, and $= 0$ when each oscillation begins with zero stress, and $+ 1$ when the stress is invariable.

$n=-1.$	$n=-0{\cdot}75.$	$n=-0{\cdot}5.$	$n=-0{\cdot}25.$	$n=0.$	$n=+0{\cdot}25.$	$n=+0{\cdot}5.$	$n=+0{\cdot}75.$	$n=+1.$
369	424	487	563	663	780	940	1,077	1,268

The stress here given is in kilograms per square centimetre, and represents the greater of the two stresses (tensile or compressive) to which any piece should be subjected. The value, however, for $n = +1$ is extraordinarily high, and for $n = -1$ is extraordinarily low.

The Author then proceeds to show that the adoption of these mean values really involves the application of a nearly constant factor of safety of 3·2 or 3·3 to Wöhler's results; and discusses the arbitrariness of this figure, arguing that to justify it the proof is necessary :—

1. That the sum of the errors which may occur in the assumed data are in a constant ratio to the sectional area to be provided.
2. That the danger involved in a transgression of Wöhler's figures has a constant value for all values of n; and
3. That the amount of error and the magnitude of the danger are correctly estimated in the above factor of safety:

no one of which suppositions can possibly be true.

In very many cases formulæ based on the experiments result in giving a smaller sectional area to the various members of a girder than is customary under the existing practice; and, though the advantage of effecting a saving in material is incontestable, it is at least strange how a process, which claims to be based on the necessity for additional security, can secure this by a general diminution of the sectional dimensions of the bars.

The Paper concludes with a practical suggestion in designing bridgework; viz., to sort the various members into classes, and allow different maximum limits of stress in these classes. Those pieces, *e. g.*, as to which no uncertainty exists, may safely be subjected to higher stress limits than those less favourably situated, either as regards possibility of accurate calculation or mode of application of the load.

T. H. E.

Foundations in the Open Air and under Compressed Air.

By M. Lébeaux.

(Annales des Ponts et Chaussées, 6th series, vol. i., p. 323, 2 pl.)

The various processes employed for laying the foundations of four bridges, recently erected over the rivers Isle and Dordogne, are described at length in the article; and more particularly a new process in which a caisson-cofferdam, composed of several pieces easily detached and removed, was sunk by the aid of compressed air. Five distinct processes were adopted in these foundations, each being selected as the most suitable to the special conditions of the individual case.

Foundations of Laroche Bridge.—The depth of the river Isle, at the site of this bridge, varies between about 8 feet and 10 feet, and the bed of the river consists of a thin layer of gravel, overlying a moderately compact limestone formation. A cofferdam, consisting of a double row of piles and sheeting, with a solid filling of earth between, was employed in this instance for enclosing the foundations of the piers. The cost of the foundations, up to 4 feet above low-water, was £4 9*s.* per cubic yard, exclusive of the cost of pumps. This common system can only be conducted with advantage when the work is carried out in the dry season; when the top bed of gravel is thin, so that the preliminary dredging does not occupy long; when the river is not subject to sudden high floods in the summer, and when the piles can be driven firmly into the stratum below the gravel.

Foundations of Beynac Bridge.—The river Dordogne, over which this and the Pech and Garrit bridges are built, has not a regular and tranquil flow like the river Isle. Occasionally the river rises, in the portion of its course where the bridges are situated, to a height of 23 feet, and not unfrequently as much as 16½ feet; and low water can only be calculated on with any certainty in July, August, and September. Moreover, the depth of water and the thickness of the layer of gravel overlying the rock are very variable; and the limestone rock is too hard for piles to penetrate it.

Two different systems were adopted for the foundations of the four piers of the Beynac bridge. The site of the pier nearest to the right bank, where the depth of water is small, was enclosed by an embankment, joining the bank at each end. The excavation for the foundations of the pier was then carried down by timbering through the thick deposit of gravel to the rock, and kept dry by pumping. This plan is very economical, but it necessitates a considerable pumping power; and a small flood might destroy the embankment and undo the work. The foundations for this pier were completed in forty-five days, and they cost £3 10*s.* per cubic yard, exclusive of the price of the pumps. Throughout the article the foundations are reckoned to be carried up 4 feet above low-water, or the summer level of the river. The surface of the rock at Beynac is fairly level at a depth of 10 feet below low-water. It had been proposed to found the second pier from the right bank, in the same manner as the first; but the water remained too high, so the three remaining piers were founded in bottomless timber caissons. The caissons were lowered on to a foundation prepared by divers; they were weighted with rails, and made as watertight as possible by a mound of puddled clay round the bottom, and a covering of canvas nailed to the outside of the caisson, with a flap, 6½ feet long, resting on the bottom, weighted with a second mound of clay. A sump was then sunk inside the caisson, beyond the site of the foundations, and the water pumped out. This system is simple, and generally satisfactory, but the preparatory dredging occupies a considerable time, and is liable to be impeded by floods; the work, however, was much expedited at Beynac by the use of a steam dredger. The caissons in this instance were not injured by small floods; but the system is not suited to withstand winter floods. The two centre piers were founded in fifty-one and fifty-seven days respectively. The foundations, however, of the last pier, adjoining the left bank, occupied nearly five months, owing to the water bursting up through a thin crust of rock upon which the caisson partially rested. It was found necessary to break through this crust, and timber down to the solid rock, surrounding the base of the timbering with a puddle mound. The foundations could not even then be pumped dry, so the first two courses, round the outside of the pier, were laid by divers, and the space outside between them and the rocky crust, and even under it as far as possible, was filled with cement concrete deposited under water. This example indicates the value of laying dry the bottom of a foundation, for had the foundation of the pier been formed of concrete deposited under water, an accident would have inevitably occurred; it also shows the importance of carrying trial borings down into the rock more than the 4 to 8 inches which was done in this instance. The works for this last pier were protracted into the period of the winter floods, and had a flood occurred before their completion they would have been destroyed. The cost of the foundations per cubic yard, exclusive of the cost of the pumps, was £4 and £5 3*s.* for the second and third piers, and £7 9*s.* for the fourth pier.

Foundations of Pech Bridge.—A change in the direction of the railway under consideration, from St. Denis to Buisson, delayed the commencement of the Pech and Garrit bridges till 1880, the other contracts having been let in 1879. Rapidity of execution was consequently essential for these bridges; and the method of compressed air was resorted to for the piers in the river, so that the foundations might be finished in time for the arches to be built during the period of low water, and the bridges thus completed in a single season. The foundations of the four river piers of the Pech bridge had to be laid more than 13 feet below the water level, so that the ordinary method of sinking wrought-iron caissons into the river-bed by the aid of compressed air could be advantageously adopted. The foundations of these piers were completed by the end of May. The average cost of the foundations of each pier was £4 12*s.* per cubic yard. The excavations for four other piers beyond the regular river-bed were executed by carrying down timbering.

Foundations of Garrit Bridge.— Whilst rapidity of execution was as necessary for this bridge as for the preceding one, the depth of water did not exceed 6½ feet. The foundations for two of the six piers could be easily executed by enclosing them within embankments connected with the bank. The four remaining piers had to be founded differently. The employment of the bottomless timber caisson method for all the piers might have occasioned delay, especially as the current is very strong in flood time at that part of the river. Accordingly only two piers were founded by the ordinary caisson method, in fifty-five and seventy-seven days respectively, and two by the new caisson-cofferdam method, with compressed air, the first in forty-five days (having been delayed by a flood), and the second in fifteen days.

The caisson-cofferdam, constructed in separate pieces and capable of being entirely removed, was invented by M. Montagnier about three years ago, and was suggested by him for this work; his object was to employ compressed air economically for foundations in shallow water. The apparatus consists of a large bell or roofed caisson, about 16½ feet high, into which the air is forced, and inside which the foundations are excavated and the pier commenced. The caisson is made of the shape of, but larger than, the pier to be built. It is formed of wrought-iron plates, joined together by angle-irons and bolts, and packed at the joints with india-rubber strips. Two circular air-locks, and one larger central elliptical air-lock, afford easy access to the caisson. The caisson is floated into place between two boats, which can be relieved of a portion of its weight, if necessary, by the counter-pressure of compressed air. The caisson is then sunk by putting a load of pig-iron on the roof, which is strengthened by girders. The same caisson was used for the two piers. The foundations and first course of masonry of the pier were executed under compressed air. Wooden blocks were driven from the inside, between the rock and the bottom edge of the caisson; and a layer of concrete, from 4 to 6 inches thick, deposited round the base, kept the blocks in place. The roof was then taken off, and the caisson bearing on the wooden blocks was sufficiently watertight to enable the water to be kept down by pumping; and the pier was finished in the ordinary manner. A flood 16½ feet in height occurred when the work of the first of the two piers was in progress, but the precautions taken of weighting the caisson very heavily, and opening communication with the outer air, prevented the slightest damage being done, though the water flowed over the caisson and the current was very strong. The average cost per cubic yard of each pier, up to 4 feet above low water, founded by means of a timber caisson, was £5 14*s.*, whereas the cost reached £9 14*s.* with the new method. Though the new system was costly, it enabled a whole season to be saved; also the cost in this instance was in a great measure due to the small depth, 6½ feet, of water, for which it was used, and it would be much reduced by the employment of the same apparatus for a number of piers.

The use of compressed air for foundations has the advantage of enabling them to be carried on at almost any period of the year, and with great regularity. The ordinary method, however, of using it is not suitable for very small depths, as the working chamber is generally 6½ feet high, and the masonry on the top for sinking the caisson has usually to be raised 3¼ feet at least; the cost, moreover, in such cases, is excessive, as the whole of the ironwork of the caisson has to be left in the work. The methods of open-air foundations are not subject to these objections, but they can only be employed when a river is low, and are not suited to cope with floods or unforeseen difficulties. They are much cheaper for small depths if everything goes well, but are liable to be much more costly if any hitch occurs. In fact, the advantages of the ordinary compressed-air system vary with the depth, and the cost varies inversely as the depth, whilst the exact opposite is the case with open-air foundations. It appears that the border line of the two systems lies between the depths of 13 feet and 16½ feet, compressed air being best above 16½ feet, and open air for depths below 13 feet. The new caisson-cofferdam, whilst possessing the advantages of compressed air for foundations, avoids its disadvantages; it enables all the difficult portions of the foundations to be overcome by compressed air, and the remainder of the work can be done in the open air. The conversion of the caisson-cofferdam, from the compressed-air system to the open air, is effected by merely removing the roof, which can be done in half an hour, or the roof can be replaced, if necessary, in the same period. The only objection to the new system is its cost, but the Author considers that, if it comes at all into general use, the adoption of the same apparatus for several piers, which can be readily done by adding or removing plates according to the size required, would make it from 20 to 25 per cent. cheaper than the ordinary compressed-air system.

The following Tables furnish a comparison of the cost and time of construction of the foundations of a pier laid by the various methods described, in depths of 6½ and 13 feet of water respectively, eliminating all modifications due to special circumstances, and making allowance for the saving that would be effected by using the caisson-cofferdam over again:—

FOUNDATIONS in ABOUT 6½ FEET DEPTH of WATER.

——	Embankment.	Bottomless Caisson.	Caisson-Cofferdam.
	£. s.	£. s.	£. s.
Average cost price per cubic yard	3 13	5 12	4 12
Average price of a pier up to 4 feet above low water	400 0	640 0	520 0
Probable duration of work . .	30 to 40 days	40 to 50 days	15 to 20 days

FOUNDATIONS in ABOUT 13 FEET DEPTH of WATER.

——	Cofferdam.	Embankment.	Bottomless Caisson.	Compressed Air, ordinary system.	Caisson-Cofferdam.
	£.	£. s.	£. s.	£. s.	£. s.
Average cost price per cubic yard	4	3 1	4 12	4 12	3 13
Average price of a pier up to 4 feet above low water .	800	600 0	1,000 0	1,000 0	720 0
Probable duration of work .	40 to 50 days	30 to 40 days	40 to 50 days	20 to 30 days	20 to 30 days

L. V. H.

Railway Bridge over the Save, near Brod.

By OTTO BECK VON NORDENAU and ALBIN JUDA.

(Mittheilungen über Gegenstände des Artillerie- und Genie- Wesens, 1880. Supplement to Nos. 10 and 11.)

In 1878, when Bosnia and the Herzegovina were occupied by the Austrian army, it was considered necessary for military purposes, that the above bridge should be constructed to serve the double duty of transporting the ordinary road traffic, and carrying a single line, connecting the Bosnian and Dálja-Brod railways, it being of importance that the works should be completed as early as possible. The site of the bridge is at a short distance west of the fortress of Brod, crossing the Save where the stream is divided into two channels by a narrow islet. The structure comprises five main openings and a number of minor flood-ways, the clear span of each of the former being 187 feet, bridged by girders of about 265 feet 9 inches in length, supported on timber piers, the centre of which are 32 feet 10 inches from the ends of the girders. Each pair of main girders is separated from those of the adjacent spans by a space of 2 feet 6 inches, across which the line is carried on the rail bearers, with expansion arrangement. The main girders are of wrought iron, 29 feet 6 inches in depth, and 22 feet 6 inches apart, centre to centre, each girder being divided into twenty bays of 13 feet 2 inches, with vertical and diagonal bracing, the four centre bays being counter-braced. The gauge is 4 feet 8½ inches, and the rails are carried by rail-bearers 2 feet deep, between the cross girders, which are 3 feet 3 inches deep, and 13 feet 2 inches apart, resting on the lower flanges of the main girders. A sufficient space exists between the rail-track and the main girders on either side for road traffic, except at the passing of trains, which are few in number. The main girders are also connected together overhead, at each vertical, by a braced framing 4 feet 11 inches deep.

To expedite the completion of the undertaking, the piers and supports throughout were made of timber. The river piers are formed by groups of round piles, varying from a hundred to a hundred and thirty in number, the twenty-four outer ones being driven to a rake of 1 in 10. Springing from a platform above this group is a second tier, 22 feet 10 inches in height (including the folding wedges upon which the girders rest), composed of a group of forty-eight vertical and thirty-two raking rectangular timbers, 14 inches and 12 inches in section. The height from high-water level to the under side of the girders is 18 feet 4 inches. The works were commenced in October 1878, but floods occurred almost immediately, preventing the works being proceeded with until mid-December, and after further interruptions from the same cause, the last pile was driven on February 15, 1879, and the second tier of vertical timbers commenced. Some of the piles were 54 feet long, and in most instances driven to a depth of 23 feet into the river-bed, the water averaging 31 feet in depth.

On the 27th April the piers and temporary stagings for the erection of the girders were completed. The construction and erection of the iron-work was undertaken by five separate manufacturing firms, and were put up in six weeks. The testing of the girders took place on the 2nd July, and the bridge was opened for traffic on the 5th July 1879. The test load consisted of two engines of 36 tons, and one of $34\frac{1}{2}$ tons, besides which was a laden lorry, &c. The temporary deflections varied from $\frac{11}{32}$ to $\frac{9}{16}$ of an inch, and the permanent set from $\frac{1}{16}$ to $\frac{3}{16}$; no settlement was observable in the piers. Running at high speed was not tried, as it was intended to travel slowly at all times, on account of the temporary character of the piers. Numerous drawings and details of the structure are given; also the calculation of strains, in which a wind pressure of 30·8 lbs. per square foot was assumed, and a diagram showing graphically the rate of progress of the works.

The average weight of iron in each main span is 318·2 tons; and the total cost of the whole structure, including timber piers, iron-work, flood openings, temporary sheds, &c., amounted to £91,600.

A Table of the details of prices is given, that for wrought iron, erected, being £25 11*s.* 6*d.* per ton.

D. G.

Renewal of Niagara Suspension Bridge.[1]

(Scientific American, 1881, vol. xlv., p. 31.)

The Niagara bridge was opened for railway traffic in 1855, and some years ago suspicions were entertained that the wire cables and anchorages were not as sound as when first constructed. In

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[1] An illustrated article descriptive of this work will be found in "Engineering," August 5, 1881.

February 1877, Mr. T. C. Clarke, M. Inst. C.E., examined the cable near one of the shoes, and found some of the wires corroded quite through. Further tests showed that the outer layer alone was affected, the second layer of wire being sound and bright. The evident cause of the corrosion was the elongation and contraction of the strands under passing loads, which had loosened the cement from the outside strands, allowing moisture to work in. The defective wires were cut out, and new ones spliced under strain, and attention was then directed to the anchor-chains and suspended girder. New anchor pits were sunk in the rock, and new anchor plates and links were fixed and thoroughly grouted with cement. In renewing the old wooden suspended girder, steel was used for the posts, chords, track stringers and lateral rods, and iron for all other parts. An automatic truss adjustment, consisting of a bent lever and wedge, with long rod attachment, was fixed at each end of the suspended girder, the arrangement being such that the latter was automatically wedged slackly against the abutments under all degrees of temperature. Some provision of this sort was necessary for the efficient action of the auxiliary straight suspending cables radiating from the top of the pier to the floor of the bridge. The total suspended weight between the towers in the new bridge is 1,050 tons.

B. B.

On the Construction of the Second Avenue Line of the Metropolitan Elevated Railway of New York. By G. T. Hall.

(Trans. Amer. Soc. C.E., 1881, vol. x., p. 107.)

The above is a double line of railway, about 7½ miles in length, of tho ordinary gauge, and with curves in some instances of 110 feet, or but 1⅔ chain radius. The permanent way consists of 63-lbs. steel rails, and 6-inch square pine sleepers, spaced generally 18 inches apart, centre to centre. Guard timbers are laid on both sides of the rails, 10 inches apart. On curves of less than 600 feet radius a steel guard rail is spiked down inside of the inner track rail, and the guard timbers and arrangements generally are of an exceptionally substantial character. The standard pier is a wrought-iron "Phœnix" column, socketed into a cast-iron bed-plate, 4 feet square, which was bolted to a mass of brickwork about 7 feet square. About three-fourths of the foundations, however, required to be special, on account of the interference of pipes and otherwise. The cement used appears to have had only the low tensile strength of from 60 lbs. to 80 lbs. per square inch after seven days' immersion in water. The superstructure consists of four lattice girders, set in pairs under each track. The girders are 4 feet deep, and weigh about 1·30 lb. per lineal foot. Details of cost and other practical information are given in the paper.

B. B.

Intercommunication in Cities. By Prof. L. M. Haupt.

(Proceedings of the Engineers' Club of Philadelphia.)

The rectangular system in which the streets of Philadelphia are laid out is found to be inconvenient to persons who wish to traverse the city diagonally. Every such person must lose 42 per cent. of his time in travelling between the termini of his route, and the Author proposes to construct several diagonal lines of communication between distant parts of the city. The parts which would be most benefited by the proposed streets contain a population of 500,000, a large percentage of whom may be obliged to cross the heart of the city diagonally.

Six of the street railway companies out of the twelve in the city carried last year 50,855,280 passengers, and assuming the other six to have carried nearly the same number, more than 100,000,000 people must have ridden in the street cars. The expenses of these railways have been, for the year, 1,990,088 dollars, making the cost per passenger only 2 cents. Assuming the average distance travelled by each person in the cars to be 4 miles, the cost per mile per individual would be half a cent. If, then, the distance could be lessened by only 1 mile it would effect a saving to the companies of half a million of dollars.

This is only the direct pecuniary advantage, and the economy of time and labour must also be considered. The foot-passengers far outnumber the car-passengers, but taking them only at an equal number, and the pace of a good walker at 4 miles an hour, then the saving of 1 mile of distance would be an economy of 25,000,000 hours; and as the average speed of a street car is about double that of a man, the saving in this respect would be half that time. It is assumed that a man walking 23 miles on a horizontal road does as much work as if he lifted his body up a vertical ladder through a height of 1 mile; hence in walking 1 mile he must raise himself 230 feet. And these are the results of the movement of persons only, and do not include the immense amount of merchandise.

If a route of 23,000 feet, as at present, were shortened to 16,000 feet, as is proposed by the Author, the saving of distance would be 1⅓ mile for every person required to move diagonally across the heart of the city, with the same percentage of saving for any part of the distance. It would open up more than 12 miles of building frontage, which would accommodate far more people than would be displaced by such an improvement.

In a rectangular system of streets the basis of calculation of the relative areas of streets and buildings is contained in a Paper on "The Best Arrangement of City Streets," published in the Journal of the Franklin Institute, for April 1877, in which it is shown hat the percentage of street to building area may be expressed by the formula $100\left(\frac{2\,l\,w + w^2}{l^2}\right)$, in which l represents the length of one side of a square of any size, and w the width of the street bordering two sides of it; and in the two great diagonal avenues proposed by the Author for Philadelphia, each 100 feet wide, $1\frac{1}{3}$ per cent. of the building area of the large square proposed to be cut through would be taken up by them, and the population disturbed would be in the same ratio, whilst the building frontages would be increased by more than 7 per cent.; so that instead of driving out the population, it would enable more to settle in the very heart of the city.

The population of Philadelphia in 1880 was 846,980, and the area of the whole city is 82,792 acres; but 500,060 people occupy 5,511 acres, being at the average rate of 90 per acre. Within this area 343,139 people occupy 3,227 acres, being at the average rate of 106 per acre. Within this area, again, 113,265 people occupy 870 acres, being at the average rate of 130 per acre; and of this inner area there are 122 acres, the population of which is 150 per acre.

The first part of the Paper having treated of the street system, distribution of population, and necessity for additional avenues in certain directions, the second part deals with the railways in and around the city, all of which, with one exception, cross the streets on the level. The district over which the local movement of traffic is considered is limited within a radius of 10 miles round an assumed centre of the city. The distances from this centre to the several railway termini vary from 2,871 feet to 14,571 feet. The time occupied in traversing these distances on foot and by horse car varies from eleven minutes on foot and five and a half by car for the short distance, to fifty-eight minutes on foot and twenty-nine by car for the longest distance, the times being calculated from the observed average rates for street cars propelled by horses, which is found to be very nearly 500 feet per minute, or 5·7 miles per hour. The rate for pedestrians is taken at one-half that, or 250 feet per minute. The average running time of the accommodation trains, including stops at intervals of 1 mile, is about three minutes per mile, so that to reach the outside of the assumed district thirty minutes must be added to the time of running.

On one of the lines of railway within the city there are ninety-nine level crossings, or to use the American term, grade crossings, of streets; on another line 292; on a third 35; and on another 12. To determine as nearly as possible the aggregate of the large number of daily trains, both ways, passing the numerous crossings, the number of crossings on any branch is multiplied into the number of trains on that branch, and thus is obtained the equivalent number of trains passing any one crossing, and these products are called train-crossings, as the analogue of "foot-pounds." The total number of trains passing any one crossing per day is 22,000. If eighteen hours be assumed as the length of the day for railway operations, these 22,000 train-crossings must be made at the rate of twenty per minute, or in other words there must be a train upon twenty crossings every minute of the day; hence the great obstruction and danger.

By the construction, in one direction, of a tunnel, and in another of an elevated railway, together with the opening out of the diagonal avenues before-mentioned, the number of train-crossings would be reduced by about 11,000, and enable the trains to make better time with less risk to all parties.

C. Sl.

Apparatus for Measuring the Comparative Strength of Broken Stones.

(Bulletin du Ministère des Travaux publiques, January 1881, p. 15.)

Since this apparatus was previously noticed,[1] the Commission of National Highways, in France, commenced its trials, in May 1879, in the Trocadero. The number of revolving inclined cylinders has been increased to eight, four and four on two parallel shafts, revolving together. Five kilogrammes, or 11 lbs., of the sample to be tried is introduced into each cylinder, and closed up, when the machine is rotated regularly at the rate of two thousand turns per hour, by the power of a gas-engine of 1 HP. At the end of five hours the apparatus is stopped, and the contents are emptied into iron basins. They are thrown into two sieves, having meshes of 1 centimetre and 16 millimetres respectively, or 0·40 inch and 0·064 inch. What passes through the second mesh is treated as dust, and weighed. The best materials rarely yield less than 2 per cent. of dust. The relative resistances of the materials to disintegration are trustworthily indicated by the proportion of dust generated in this manner.

D. K. C.

The Regenerative Furnaces at the Munich Gas Works.

(Dingler's Polytechnisches Journal, May 1881, p. 293.)

The retort settings heated by regenerative furnaces which were constructed at the Munich Gas Works in 1878, from the designs of Dr. N. H. Schilling, the engineer of those works, have undergone some alterations which have caused a considerable improvement in the working results. In the regenerator, which is situated beneath the retort setting, the zigzag arrangement of the flues for the waste gases has been replaced by horizontal flues running parallel with the retorts, and the distance now traversed by the gases is double that under the previous arrangement. Originally the waste gases left the regenerator at a temperature of 800° C.; now the temperature is 600° C. After leaving the regenerator the waste gases pass under and around a water tank placed under the grate of the generator. By this arrangement steam is produced through the waste heat, and the steam, rising through the fire-bars and becoming decomposed in the generator, adds to the quantity of combustible gas produced, and at the same time serves the purpose of cooling the furnace and fire-grate and keeping the bars from melting.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lvii., p. 331.

When Bohemian coal was used, 50 kilograms of steam per 100 kilograms of coke used sufficed to prevent the formation of clinker in the furnaces, and this quantity the tank was capable of producing. When, subsequently, Prussian coal from Saarbrück was carbonized instead of Bohemian, it was found that 70 kilos. of steam were required per 100 kilos. of fuel used. This quantity being more than the tank produced, the latter was lengthened and a tube inserted lengthwise for the return of the hot gases, after which the yield of steam was sufficient for the requirements of the generator. The gases then possessed a temperature of 500° C. on leaving the tank and entering the main flue.

The secondary air-supply was formerly heated to 600° C., now it acquires a temperature of 1100° C.

In the autumn of 1879 the retorts were maintained at too high a heat, and, as a consequence, the tar produced became very thick, and stopped up the ascension pipes and the hydraulic main. At the same time serious deposits of naphthaline took place, not only in the works, but also in the street mains. At this time the make of gas equalled 10,500 cubic feet per mouthpiece per diem, the charges of coal being of three hours' duration. The temperature of the retorts was then reduced, so that the make per mouthpiece was about 9,000 cubic feet per diem, and the duration of the charges was extended from three to four hours. Under these conditions no difficulty was experienced in the working. The following are the average results produced when carbonising Saarbrück coal only:—

Gas produced per 100 kilos. of coal carbonised = 105 cubic feet.
(about 10,500 feet per ton.)
" " mouthpiece per diem =9,030 cubic feet.
Coal carbonised " " " = 861 kilos.
(about 17 cwt.)
Fuel used per 100 kilos. of coal carbonised = 14 kilos.

Comparing these results with those previously obtained, it is found that the fuel used is less by 20 to 26 per cent.; while, owing to the reduction in the heat of the retorts, the gas production is 5 per cent. less.

The average constitution of the generator gases is as follows:—

	Per cent.
Carbonic acid	9·1
„ oxide	19·8
Hydrogen	13·9
Nitrogen	57·2
	100·0

The quantity of steam introduced was 72 kilograms per 100 kilograms of carbon consumed.

The following is the analysis of the waste gases on leaving the retort setting:—

	Per cent.
Carbonic acid	18·6
Oxygen	1·2
Nitrogen	80·2

After passing through the regenerator the gases contained:—

	Per cent.
Carbonic acid	17·2
Oxygen	2·8
Nitrogen	80·0

A saving has also resulted in the wages of the stokers, &c., the cost of carbonising 100 kilograms of coal being now 57·26 pfennige as against 80·3 pfennige previously.[1]

After twenty-one months' working neither the generators nor the regenerating flues require the least repair, both being in perfectly good working condition.

G. E. S.

Explanation of a Hydrodynamical Paradox.[2] By G. A. Hirn.

The Author states two well-known theorems:—(A) The pressure of a jet on a plane, normal to its direction, is equal to the weight of a prism of fluid, having for base the section of the jet, and for height twice the height due to the velocity. (B) The reaction on a vessel of a jet escaping from it is also equal to the weight of a prism of base equal to the section of the jet and length equal to twice the height due to the velocity. Calling S the section of the jet, H the height capable of producing the velocity V, and G the weight of a cubic unit of fluid—

$$P = 2\,S\,H\,G = 2\,S\,G\,\frac{V^2}{2\,g}.$$

From the equality of action and reaction, if one of these theorems is true, the other is so necessarily. But the second leads to an apparent paradox.

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[1] A pfennig = $\frac{1}{100}$ of a mark or shilling.—Abstractor.

[2] The original pamphlet, "Explication d'un Paradoxe Dynamique," will be found in the Library of the Inst. C.E.

The Author then discusses the experimental evidence for (A). In order that (A) may be true, the fluid particles striking the plane must lose their velocity or leave the plane at right angles to their initial direction. The former condition would be satisfied if the jet fell vertically into a vessel of water, an experiment which does not appear to have been made. In experiments on the impact of jets on planes the second condition is not exactly satisfied, chiefly because of the rebound of the water. It is not surprising, therefore, that (A) is not exactly verified by experiment. As to theorem (B) the Author deduces from the action of turbines an experimental confirmation.

Now, let water flow under a constant head, H_0, from an orifice of area S_0, then from theorem (B), the effort of recoil is

$$P = G\, S_0\, 2\, H_0.$$

The origin of half the effort of recoil is easy to understand. Suppose the orifice fitted with a piston, held in place by an obstacle independent of the vessel, the effort exercised on the piston would be

$$P = G\, S_0\, H_0,$$

and as that pressure is exercised on a surface independent of the vessel, the latter must be pressed back by an equal force. But the moment the piston is removed, and the water allowed to flow freely, the tendency to recoil doubles. Whence is derived this effort, and how is it exercised on the sides of the vessel? The pressure on the side opposite the orifice is not altered by the removal of the piston. But the pressure may be diminished on the side in which the orifice is, and, in fact, this is what takes place, as can be shown, without mathematical analysis, in an approximate form.

If an orifice is pierced in a thin plate, the volume discharged differs considerably from the volume improperly called the theoretic discharge, and which is given by the equation

$$W = S \sqrt{2\, g\, H_0}.$$

The coefficient of reduction by which this expression must be multiplied is 0·6 to 0·64. The reduction of discharge is due almost entirely to contraction of the stream and not to diminution of velocity. That single fact gives almost completely the explanation of the paradox. Suppose that to the orifice a mouthpiece is added of the form of the contracted stream, it is obvious that the hydrostatic pressure will be zero over the whole surface of that mouthpiece. Let S_1 be the section of the contracted part of the stream. A frictionless piston applied to that part would be pressed with a force $G\, S_1\, H_0$ and the vessel would tend to recoil with the same effort. In statical conditions the mouthpiece would support a pressure parallel to the axis equal to

$$G\left(\frac{S_1}{0\cdot62}-S_1\right)=G\,\frac{0\cdot38}{0\cdot62}\,S_1=0\cdot613\ G\ S_1.$$

At the moment the piston is removed and flow established this pressure would disappear, and the excess of pressure on the opposite side of the vessel would become, at least,

$$P=G\,H_0\left[\left(\frac{S_1}{0\cdot62}-S_1\right)+S_1\right]=1\cdot613\ G\ S_1\ H_0.$$

The excess is really 2 $G\ S_1\ H_0$, but analysis is necessary to prove this. The Author then considers mathematically the diminution of pressure in the elementary streams approaching the orifice and establishes his conclusion.

W. C. U.

Forez Canal.—Apparatus for Gauging Water Supply.

(Les Annales des Travaux Publics, June 1881, p. 375, 1 pl.)

The Forez canal draws a supply of water from the Loire for the purpose of irrigating about 19,800 acres of land in the plain of Forez. One of the most interesting of the details of this work is the apparatus designed by M. Girardon for gauging the quantity of water supplied to the various proprietors, each proprietor being entitled to receive a volume of water equivalent to 2⅔ gallons per acre per minute.

M. Girardon considered that the plan employed in Piedmont and Lombardy, of measuring the water by discharging it through an orifice at a constant pressure, was too complicated and costly. He therefore adopted the method of a waste-board with a thin edge.

Two types of the apparatus are fully illustrated in the article. The first, or smaller type, has the sluice-gate for admitting the water placed on the inner slope of the canal bank, and made of iron. The water flows through a culvert into a square regulating pond, with masonry or concrete side-walls, each 3¼ feet long, at the far side of which the waste-board is placed, leaving an opening for the discharge of the stream of water, 8 inches wide and 8 inches deep.

The second, or larger type, has the sluice-gate, made of wood, placed at the upper end of the regulating pond, whose sides are each 9 feet 10 inches long; and the opening left by the waste-board, at the opposite side of the pond, is 2 feet 1½ inch wide and 10 inches deep.

The orifice for the admission of water into the pond is so placed below the surface of the water in the pond, that no current is produced at the surface by the influx of water, which could modify the discharge over the waste-board. A sloping masonry overfall is so arranged below the waste-board that the discharge is perfectly free, and can be collected in a measuring receiver. The cost of the smaller gauging apparatus is £8 10*s.*, and of the larger type, £17.

M. Girardon had, in the first instance, drawn up a set of Tables giving the values of the discharge for every millimetre in depth of the stream flowing over the weir, calculated from the formula,

$$Q = m \, L \, e \sqrt{2g \left(y - \tfrac{1}{2} e\right)},$$

where L is the length of the sill of the waste-board; *e* the depth of the stream over the sill; *y* the difference of level between the sill and the surface of the still water in the pool, and *m* the ratio between the theoretical and effective discharge. It was discovered, however, that the actual discharges were greater than the calculated values. Accordingly, the discharges were measured for various heights of the stream over the sill, and the results plotted on paper. It was found that, taking the different heights of the stream as the abscissæ, and the quantities discharged per second as the ordinates, and joining the extremities of the ordinates, the curve thus obtained was approximately a parabola tangential to the axis of the abscissæ at the origin of the coordinates. By drawing the exact curve, any intermediate values could be ascertained, and errors in experiment rectified. From this curve a table of discharges was made for every millimetre of thickness of stream over the sill between zero and 200. A Table has been drawn up for each of the two types of apparatus; and these two Tables serve as the standards by which the actual supply is determined from the thickness of the discharging stream, which can be regulated as required.

The following extracts from the Tables, given in full by the Author, indicate the values of the measured discharges per second; and the corresponding calculated values show the discrepancies between the two:—

Height of Stream discharging over Sill.		Small Gauging Apparatus. Length of Sill, 8 inches.			Larger Gauging Apparatus. Length of Sill, 2 feet 1¼ inches.		
		Measured Discharges.	Calculated Discharges.	Differences.	Measured Discharges.	Calculated Discharges.	Differences.
mm.	Inches.	Gallons.	Gallons.	Gallons.	Gallons.	Gallons.	Gallons.
10	0·39	0·14	0·08	0·06	0·35	0·26	0·09
30	1·18	0·57	0·42	0·15	1·78	1·32	0·46
50	1·97	1·14	0·91	0·23	3·95	2·91	1·04
100	3·93	2·84	2·53	0·31	11·94	8·19	3·75
150	5·90	4·84	4·64	0·20	22·67	15·04	7·63
200	7·87	7·19	7·15	0·04	36·10	23·19	12·91

L. V. H.

New Method of accelerating the Passage of Vessels through Locks.

By A. de Caligny.

(Comptes rendus de l'Académie des Sciences, vol. xcii., p. 1265.)

The discharging culvert of the Author's apparatus for saving water in locking,[1] even when not combined with a reservoir basin, is useful for facilitating the entrance into, or exit from, a lock of ascending or descending vessels.

Much water is frequently lost by raising the sluice-doors of the upper gates in order to push a vessel out of the lock; whereas by raising the upper tube of the Author's apparatus, a small discharge of water from above draws a considerable quantity of water into the lock from the lower pool, when the water in the lock is at the same level. The lateral pressure thus produced, behind the boat, pushes it forwards without any shock.

The same principle may be adopted when the discharging culvert has outlets at each end of the lock-chamber. In the case of a vessel passing from the lock to the upper pool, the velocity acquired by the water in the culvert may be adequate to raise the water in the lock sufficiently above the water-level in the upper pool to open the gates and push the vessel into the upper pool. As the discharge, in this instance, takes place through both outlets, the culvert could be of moderate section; whilst a larger culvert might be made to communicate between it and the upper pool, and to contain the movable tubes. When the section of the culvert is not large enough to produce rapidly a sufficient difference in level of the water for opening wide out the upper gates, when the lock is filled, or the lower gates when the lock is emptied, it would suffice to check the opening of the gates for a few seconds, till the difference of level had become ample for the purpose.

The Author proposes in a future communication to show how his system is specially applicable to the case of parallel double locks.

L. V. H.

Hydraulic Apparatus for Lock-Gates at Bordeaux.

By M. Bontan.

(Annales des Ponts et Chaussées, 6th series, vol. i., p. 540, 1 pl.)

The floating dock at Bordeaux is connected with the river Garonne by two parallel locks. The large lock has a width of 72 feet, and has two pairs of gates pointing inwards, and one pair of flood-tide gates. The smaller lock, 46 feet wide, has one pair of flood-tide gates, and three pairs of gates pointing inwards, dividing the lock-chamber into two compartments.

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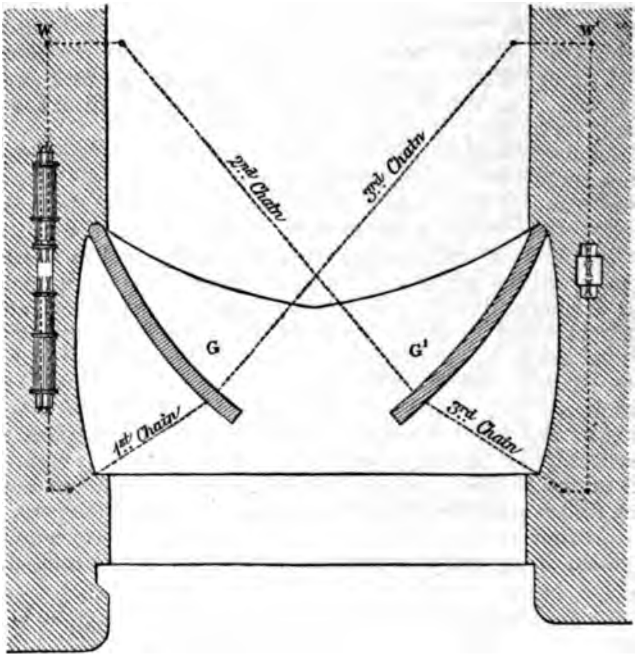
[1] *Vide* Minutes of Proceedings Inst. C.E., vol. l., p. 220, and vol. lvi., p. 337.

Hydraulic machinery has been adopted for working the gates; and besides being the first application of the system to this purpose in France, it differs in some of its arrangements from the methods adopted elsewhere.

Both gates of each pair are worked by a single hydraulic machine placed on one of the side walls, instead of a separate machine being used for each gate.

The machinery consists of two cylinders and pistons, placed endwise along one of the side walls, W, of the lock; and the pistons are so connected by chains working round pulleys, that when one piston is pushed out of its cylinder to a certain distance, the other piston enters its cylinder to a similar extent. Chains fastened to each cylinder, worked by the pistons, and guided and directed by means of pulleys, transmit the hydraulic power to the gates.



There are three distinct chains; and the manner in which they act upon the gates is indicated in the accompanying figure. The first chain, moved by the piston nearest the dock, is fastened at its other extremity to the back of the gate, G. The second chain, moved by the other piston, is fastened to the front face of the other gate, G'. The third chain, having one end fastened to the back of the gate G', passes along the side wall, W', and being guided by pulleys, is connected at its other end to the front face of the gate G. It is kept stretched, by means of a counterpoise weight, throughout the changes in horizontal length between its extremities owing to the varying positions of the gates. The weight is attached to the chain in the centre of the side wall W′, rising and falling in a well formed in the wall; and the extent of its descent is regulated by the position of a support in the well on which it can rest. By this arrangement the horizontal distance between the two ends of the third chain is shortened or lengthened by double the distance traversed by the weight, without the tension of the chain being modified; and when the weight rests upon the support, the tension ceases. The first chain acts in opening the gates by pulling back the gate G, which, drawing the third chain after it, causes that chain to exert a similar pull on the gate G′, so that both gates are opened simultaneously by the piston moving the first chain. The second chain, when pulled by its piston, closes the gate G′, which also, drawing the third chain after it, effects the closing of the gate G at the same time. Thus the first chain opens the gates; the second chain closes them, and the third chain merely transmits the movements of the one gate to the other, causing the two gates to move in absolute unison.

This mechanism has been in regular operation since October, 1879; and experience indicates that, in water free from sediment, it would work with mathematical precision. At Bordeaux this absolute precision is not quite realised, owing to the presence of silt which prevents the chains resting on the actual floor of the lock, and impedes the perfect opening of the gates. The advanced stage of the works, moreover, when the system was decided on, prevented the pulleys being placed in the most suitable positions, so as to exert the most direct pull when the resistance is the greatest. These objections, however, might be avoided in a future work where the system is decided on at the commencement.

L. V. H.

Dam across Cahokia Chute on the Mississippi.

(Report of the Chief of Engineers U.S. Army for the year 1879, part ii., appendix N., p. 1035, 1 pl., 1 woodcut.)

The construction of a dam across Cahokia Chute formed one part of the scheme for the improvement of the Mississippi, between the mouths of the Illinois and Ohio rivers. As the channel, or chute, which the dam was to close at low water, was the principal branch of the river, and the only one practicable for navigation during the low stages of the river, it was necessary to commence the dam when the river was high, so that the river might scour itself out a channel through the broad flat bar which extended across Arsenal Chute before it had fallen to its low-water level. Six rows of piles, placed a few feet apart, were driven into the river bed across the channel, the lowest row being 65 feet below the centre line of the dam, and the upper row 10 feet above it. A mat of brush was then formed, about 2 feet wide, between each row, in alternate courses parallel to and across the current, and was loaded with stone. The brush between the three up-stream rows of piles served as the foundation of the dam, and the brush between the lower rows formed the apron. In the portion of the channel near the Illinois shore, where the current was strong and the depth of water amounted to 30 feet, the employment of piles for keeping the brush in place was discontinued, and mattresses, about 96 feet long, 24 feet wide, and 2 feet thick, were sunk in position. These mattresses were placed with their length parallel to the current, and formed the foundation and apron of the dam in the deeper portion of the river channel.

The dam was about 1,500 feet in length, and was raised to about 5 feet above low water with brush and stone, and then continued up to its full height of 9 feet above low water with stone only.

The channel above the dam was deepened by scour to the extent of from 2 to 5 feet; this scour was observed to be taking place soon after the foundation of the dam had been laid.

About a week after the completion of the dam a breach, 200 feet wide, was made through it, with a depth of water of about 18 feet. The sides of the breach were protected against scour, and measures were adopted to check the scouring action which was developed above the dam, along its whole length, and threatened to undermine the dam and cause other breaches. The widening of the breach was thus prevented, but its depth had increased to about 30 feet below the water surface before the arrangements for closing it could be finally completed seventeen days after the accident. The breach was filled up with stone, varying in size from 2 to 37 cubic feet, the large stone being placed at the bottom. The operations, after being carried on for a month, were stopped by the ice in the middle of December, and the repair of the breach was finally completed in the spring.

The bar across Arsenal Chute was scoured through during the winter.

L. V. H.

Survey of the Mississippi River.

(Report of the Chief of Engineers U.S. Army for the year 1879, part iii., appendix MM, 6 plates, 1 woodcut.)

A detailed account is given of the operations of the six surveying parties engaged on the survey of the Mississippi during the year ending 30th June, 1879; and also of the survey of the northern and north-western lakes during the same period.

It was found, in levelling along a line in duplicate, and in opposite directions between Austin and Friar's Point, a distance of 34 miles, that, as in precise Swiss levellings, the levellings in opposite directions gave different results. This discrepancy is attributed to the settlement of the point on which the foresight is taken in the interval of time between the taking of the foresight and the backsight. The difference almost invariably found in these levellings amounts to a quantity that would be produced by such a settlement; and the accumulated error in a distance of 27 miles amounted to 14¼ inches.

In the course of the soundings taken of the Mississippi at Helena, it was discovered that a series of sand-waves were gradually moving down stream along the bed of the river, at an average rate of 18 feet a day, in a depth of water varying from 13 to 30 feet. These waves had an average length, from crest to crest, of 330 feet, and a maximum length of 500 feet; their height was on the average about 5 feet, and never exceeded 8 feet.

A description and a sketch are given of an apparatus called a sediment can, for collecting samples of water in a river at various depths to ascertain the amount of sediment contained in the water. This can has two completely open ends, so as to allow the water to pass freely through its entire cross-section whilst being lowered in the river, so that no accumulation of sediment takes place previous to its being closed at the required depth. The closing is accomplished by means of two hinged lids which shut simultaneously against each end of the can, the lids being drawn down by rubber bands connecting them as soon as the catches keeping them open are withdrawn.

Velocity measurements were made of the flow of the river by means of double floats, in a manner similar to that described by Messrs. Humphreys and Abbot in their Report on the Mississippi river.

L. V. H.

Improvement of the Upper Mississippi River.

(Report of the Chief of Engineers U.S. Army for the year 1879, part ii., appendix Q., p. 1103, 11 pl.)

In improving the Upper Mississippi, the parts offering the greatest obstacles to navigation have been dealt with first. The work of improvement consists chiefly in training and contracting the channel at various points by constructing numerous spur-dams projecting from the shore; and by closing the low-water channel of secondary chutes, where islands exist, by making a dam across the channel, between the island and the shore. The dams consist of mattresses of brush weighted with small stone, except on the apron and the top covering, where as heavy stone as a man can lift was used. The bottom layer of mattresses extends 10 feet down stream beyond the next layer, and the succeeding layers are each stepped back 3 feet; several plans accompanying the reports show the alterations produced in the river by the spurs and dams.

Rock Island rapids have been improved by the blasting and removal of rock, and other portions of the river have been improved by the removal of fallen trees and other obstructions, and by dredging.

L. V. H.

Improvements of the Missouri River.

(Report of the Chief of Engineers U.S. Army for the year 1879, part ii., appendix O., p. 1051, 7 pl., 6 woodcuts.)

The training of the Missouri river was commenced by the Government in 1877. Previous works by private parties had either failed or proved very costly. The bed of the river is so shifting and treacherous that it would be impossible, at any reasonable cost, to build solid dykes and revetments upon it, as they would be sure to settle till they reached the rock, often 60 or 70 feet below low-water mark.

Accordingly thin flexible mattresses of brush, in some cases not more than 6 inches thick, are being employed for securing the banks from erosion. Full particulars of the methods of construction of the various mattresses employed are given in the reports from the different places along the river where these works are being carried out. Generally the mattresses are constructed on shore and floated down to their proper position; but it has been found preferable to construct them on floating ways exactly over the site which they are to occupy when sunk, as thereby a better bond into the bank can be formed. With the boat carrying the ways used at Nebraska, 3,000 feet of mattress work were built in 10⅓ days. At one part of the river which is being trained, the river rises in flood-time 3 or 4 feet above the banks, and the current attains a velocity of 7 or 8 miles an hour; and for several years the annual erosion of the banks has amounted to 1,100 feet. Directly this erosion was stopped by protecting the banks, the bed of the river was scoured out to a depth of 30 or 40 feet below its former level.

The mattresses at the side gradually slid into the trough thus formed, and had to be replaced by new ones inside and overlapping them; and the width of the mattresses had to be constantly increased. The mattresses deposited in 1878 were about 50 feet wide, and extended up to low-water mark; whilst in 1879 they were made 120 feet and upwards in width, and extended to the top of the bank, or even beyond, to provide against future settlement. In such places it is very important to protect long lengths of bank at one time, as thereby the scour in any particular part is reduced, the safety of the work increased, and its cost diminished.

Floating brush dykes are also being employed for rectifying the course of the river, by checking the current at suitable places, and thereby causing deposit to take place. These dykes are formed by a series of weeds placed about 10 feet apart. These weeds consist of a pole or cord forming the stem, and light brush tied at intervals along the cord forming the branches; the cord is anchored to the bottom at one end, and the other end is supported at the surface by a float. These weeds accordingly, floating end up, slightly inclined down stream by the action of the current, resemble large weeds growing in the bed of the river. Training spur dykes are also formed in this manner, but in this case the space between the weeds should be small. As these dykes are destroyed by floating ice, it is important to lay them down directly the ice has disappeared from the river in the spring, so that they may produce their effect upon all the floods which occur before the following winter.

L. V. H.

The Improvement of Rivers and Harbours, in New Jersey, Pennsylvania, and Delaware, in charge of Colonel J. N. MACOMB *and Brvt. Lieut.-Colonel* WM. LUDLOW, *Corps of Engineers, U.S.A.*

(From Appendices of Reports of Chief of Engineers U.S. Army, 1879 and 1880. 8vo. Washington.)

Harbour of Philadelphia.—Philadelphia, about 100 miles from the sea, is practically at the head of navigation on the Delaware river for sea-going vessels, and its rapidly-extending commerce, calling constantly for larger vessels, of deeper draught and greater capacity, has had the effect of increasing relatively the known obstructions to navigation, and to demonstrate the existence of others to which special attention had not been attracted. Whereas in former years depths of 18 and 20 feet sufficed, at the present time ships are loaded with valuable cargoes to the depth of 25 feet.

Without the aid of the general government, which, through the custom-house, directly profits to the extent of between $9,000,000 and $10,000,000 annually from the foreign portion alone of this commerce, the necessary modifications of the channel, demanding large expenditure, could not be made. The depth of water now required approaches the probable ultimate capacity of the river and bay, since there are long stretches of the existing channel where the depth does not exceed 27 and 28 feet, and, in fact, there are few portions of the river exhibiting a depth greatly in excess of them. The points at which obstruction to navigation exist are as follows:—

1. *Near Richmond*—in the upper part of the city of Philadelphia—the 24-foot low-water channel of the Delaware is interrupted by a bar of sand, clay, gravel, and small boulders lying across the

stream, with a low-water depth upon it of 12 or 15 feet only. Above the bar, which is 700 yards across, the 24-foot channel continues for another mile until again terminated near Five-Mile Point. A channel has been dredged the present year (1879–80) through the bar to the depth of 24 feet at low water, with a width of 100 feet, and a valuable extension along the city front of 1½ mile of main-ship channel thereby secured. During the ensuing year (1880–81) the width will be increased to 250 feet, and by July, 1882, with suitable appropriation, an additional 100 feet of width, with the same depth, can be obtained, making 350 feet width in all.

2. *The Horseshoe Shoals.*—The Delaware river at this point, (opposite the lower part of Philadelphia) forms a bend of nearly 90° in 2½ miles, and widens to nearly double the width it has either above or below the Horseshoe. The channel depths through the Horseshoe are sufficient for the navigation, which is only seriously interfered with by ice in winter, gorges forming at both ebb and flood tides. In ordinary seasons the ice-boats owned by the city of Philadelphia suffice to keep a channel open through the "shoe;" but in such seasons as the last they are themselves locked up in the ice for hours at a time, until freed by the change of tide loosening the jam. The requisite measures for the improvement of this portion of the river has been the subject of investigation by officers and Boards of Engineers, and permanent works of a somewhat extensive character have been found to be necessary.

3. *Mifflin Bar, about 6 miles below the junction of the Schuylkill river with the Delaware at the southern point of the city of Philadelphia; between Fort Mifflin on Hog Island on the Pennsylvania side and Billingsport on the New Jersey side of the river.*—Between these points, which are 2¼ miles apart, the river is about 1 mile in width. The main channel passes the fort southerly on the Pennsylvania side, and continuing downwards the 24-foot curve closes at a point 1¾ mile below. Opposite Billingsport the main channel is on the New Jersey side, and the 24-foot curve forms a pocket about 1¾ miles above. The two deep-water channels therefore overlap about 1 mile, but are separated some 400 or 500 yards by the Mifflin bar, which, composed of fine sand and mud, lies longitudinally in mid-river, following the slightly double curve of its axis from above Fort Mifflin Light to Maiden Island. Vessels navigating the Delaware to and from Philadelphia must therefore cross this bar, upon which in 1873 were only 18 feet at mean low tide, and the heaviest ships could only pass on the top of the tide.

The improvement of the bar was begun in 1873, and continued yearly thereafter by dredging a cut diagonally through it to connect the two channels. The cut was at first to 20 feet, and this being found insufficient, to 22 feet. Notwithstanding the use of the channels by deep-laden screw-steamers, the cut exhibited a tendency to fill, due apparently to several causes, two of which seemed capable of modification. One was the too great angle made by the axis of the cut with the direction of the tidal currents of the river, which had caused the sides of the cut to fall in, and thus tend to obliterate the artificial channel; the other, the insufficient depth of the cut, which prevented curves deeper than 22 feet from entering it, and the beneficial effect of an energetic scour was thereby lost. During the year 1878–79 a cut 500 feet wide and 26 feet deep at mean low water, connecting corresponding depths in the two channels, had been commenced, with its axis so directed as to be nearly on the prolongation of the axis of the river above. This is intended to secure an almost direct flow through the cut of, at any rate, the lower strata of water, and presents also a favourable line upon which to construct the range-lights in contemplation by the Lighthouse Establishment. After suspension of this work during the winter 1879–80 it was resumed in the spring of 1880. The desultory prosecution of the work showed its effect in a diminution of the channel depth, but a 24-foot low-water channel about 400 feet wide has been secured. It is possible that eventually the construction of permanent works, such as a submerged dam from Hog Island, may be clearly proved necessary to aid in the maintenance of this channel.

In works of this character, where a struggle is maintained against constant natural action, time is an important factor in attaining results. If the prosecution of the work be such as to produce an equilibrium only, the struggle is made perpetual, and the solution of the problem becomes simply a question of annual expenditure. The history of this work shows that this may be put down at \$25,000 annually. In many cases, however, it is possible, by rapid work, to outstrip the opposing forces, which act steadily, without oscillation, and by taking the lead secure such results as will compel those forces to aid the work instead of retarding it. It is recommended that not less than \$50,000 be expended in enlarging the cut, both in depth and width, in order to test the question of annual expenditure or permanent improvement.

4. *Schooner Ledge*, 18 *miles below Philadelphia.*—This reef of rock, lying in mid-river between Chester and Marcus Hook, is the only one known at the present time to exist in the main channel of Delaware river or bay. The deepest water over it is 24 feet at mean low water, and this depth only obtains for 45 feet in width, and is found within 150 to 200 feet of projecting points, upon which are but 18 or 19 feet. To vessels drawing over 18 feet it is a most dangerous obstruction, and its removal is one of the most important improvements that can be made to the navigation of the Delaware. At other points on the river, between Philadelphia and the sea, delays are frequently occasioned by an insufficient depth of water or by narrowness of channel, and vessels sometimes take the bottom and lie aground; but since the channel-beds are sand or mud, serious injury is not thereby usually incurred, other than that due to loss of time. These are great inconveniences and restrictions upon commerce, but not dangers. The case is quite different at Schooner Ledge. The slightest touch is sufficient to tear off the copper, and a heavy blow necessitates docking the

vessel at a burdensome expense, in addition to the cost of repairs; while, if the shock be sufficient to stop the vessel, serious damage is inevitable. The many pieces of sheathing, crimped like paper, found by the diver upon the ledge, attest the frequency of these accidents. According to the Report of 1879 the rock is a species of gneiss, with thin veins of quartz intersecting it. Portions contain a considerable part of hornblende, which substance is replaced in other portions by mica. The principal planes of stratification, judging from the ton or more of specimens raised, stand at the high angle of 75° and 90°, with a north-east and south-west direction, and are crossed by horizontal seams of varying thickness, the whole presenting favourable conditions for drilling and blasting as far as the material itself is concerned. The locality, however, is an exposed one, and the tides, running from 2·2 to 2·5 miles per hour create a heavy sea, when opposed by the wind. Furthermore, owing to the proximity of the work to the channel, passing vessels throw a heavy wave.

According to the Report of 1880, the extent of widening of the 24-foot low-water channel at this reef by the operations during the previous year averaged 45 feet; a widening of 100 feet is nearly completed, and the work is yet in progress.

5. *Cherry Island Flats.*—The Cherry Island Flats begin just below Old Man's Point, 24 miles from Philadelphia. At this point the river is 1¼ mile wide. At Deep Water Point, 5 miles below, it is 1 mile wide. Between the two the width increases to nearly 2 miles, and the flats lie in mid-stream, dividing the river into two channels. In 1842, as shown by the general chart of the river, these flats were covered with from 8 to 12 feet of water. They have since risen, until over a considerable area there are now but 1½ foot. The 18-feet curve, however, occupies about the same position as formerly.

The general plan of improvement was the construction of a 24-foot low-water channel on the west side of the Cherry Island Flats, the original depth being 18 feet. The average length of the new channel is 3,500 yards, and the operations to July 1, 1880, have taken out about 300,000 yards of mud, and effected a channel 24 feet deep at low water, with a clear width at bottom of 110 feet. The material removed is a soft mud, with a moderate intermixture of sand; and it was found, after making the first cut 40 feet wide, that the sides filled in rapidly, so that on completing the second cut the lower part of the first had again to be opened. This filling-in continued until the third cut had been made, when the increased volume of tide passing through the cut began widening the artificial channel at both ends, thereby shortening the lengths of succeeding cuts. The indications are strong that, as the width of the channel is increased, the currents will traverse it with sufficient force to materially aid the dredging operations.

6. *Bulkhead Shoals, 36 miles below Philadelphia.*—About 4 miles from Fort Delaware the river changes its direction through an angle of about 68° from south-west to south-south-east and divides

into two channels, which unite again about 2 miles below the fort. The western channel following the concavity of the shore is principally used by lighter draught vessels, especially in winter when the northerly winds drive the floating ice to the eastern or main channel. This eastern channel has a depth about 6 feet greater than the western, and is usually navigated by all vessels. The two channels are separated by Bulkhead Shoals, near the upper end of which the main channel depth decreases to 22 and 23 feet, with a limit of about 21 feet on the straight course lighted by Deep Water Point range. It is proposed to remove this ridge, which, on the line suggested, has only 18 or 20 feet upon it, by dredging over an area about 1700 yards by 100 yards to a depth of 24 feet of mean low water. This improvement was begun in 1880; but the existence of a wreck near the upper end of the shoals, had produced so considerable changes as to indicate the necessity for removal of the same before proceeding with dredging. Operations on Bulkhead Shoals will be proceeded with the ensuing year and continued in 1882.

7. *The Dan Baker Shoals, about* 49 *miles below Philadelphia,* have been subject of complaint from insufficient draught, narrowness and changes of direction. The difficulties encountered are chiefly due to imperfect information, and suggest the necessity of accurate and recent charts, as the channel depths of the bay are sufficient.

The Schuylkill River.—The city of Philadelphia is situated at the junction of the Delaware and Schuylhill rivers, the improved territory of the city commencing about 2½ miles above "League Island," which forms the point of junction. With the avoidance of the "Horseshoe" and some facilities of railways, this river has become of late years an important part of the harbour of Philadelphia.

8. In 1870 when the work of improvement of the river was begun, the channel entrance from the Delaware had a mean low-water depth of about 15 feet, with only 12 feet between Girard's Point and Gibson's Wharf. Down to July 1879, over 660,000 yards of material have been removed from the channel; since this date 239,000 yards have been removed, the depth secured being 24 feet at low-water to Girard's Point, and thence to Gibson's 20 feet.

The use of this improved river for the year ending June 30, 1880, was: in grain shipments, 94 seagoing steamers, and 272 ships and barques, with 54 smaller vessels—420 in all—carrying 13,286,247 bushels of grain. In petroleum shipments, 47 ships and barques, with 154 smaller vessels—601 in all—carrying 1,772,216 barrels of petroleum. The vessels loading in the Schuylkill for foreign ports with grain and oil require not less than 25 feet, and have gone to sea drawing nearly 27 feet.

Delaware Breakwater Harbour.—This great harbour of refuge was appropriated for in 1828, and its construction begun the following year. The project contemplated the building, in the concavity of the bay, just inside of Cape Henlopen, of two massive works on the rip-rap system, separated by a gap; the southernmost and longer of the two, called the breakwater, to afford a safe anchorage during gales from the north and east; the other, called the ice-breaker, to guard the shipping against north-westerly gales and the heavy drifting ice of the bay. The stones used varied from ¼ ton to seven tons in weight; the smaller constituting the bulk of the mass, the larger used to cover the exterior slopes and sustain the direct impost of the sea. The breakwater is 853 yards long on the top; the ice-breaker, 453; the gap is about 440 yards in width. The average width of both the breakwater and ice-breaker is 22 feet on top and 160 feet at the base, the top being about 14 feet above mean low water. By 1839, 835,000 tons of stone had been deposited at a cost of $1,888,000; subsequently irregular appropriations were made, resulting in a final expenditure, up to 1869 of $2,123,000 (the quantity of stone deposited after 1839 is not recorded in the reports).

There are still, as might be supposed, indications of movement and subsidence in the masses, but the work remains substantially as left in 1869.

The breakwater harbour has now for many years fulfilled its purpose so far as its capacity would allow; but the growth of commerce has exceeded possible anticipation, and practically excludes more than a fractional part from the intended shelter. The number of vessels anchoring in the harbour and vicinity during the last year reached a total of 14,000, having a tonnage probably in excess of 600,000, with a value, irrespective of cargoes, probably in excess of $100,000,000. For a commerce of this extent, exposed during every month in the year to the storms of the Atlantic, no shelter other than the breakwater harbour exists between Cape Henry and Sandy Hook.

According to a special report of Colonel William Ludlow, this breakwater harbour has been for some years and is now deteriorating: first, by the advance northward and westward of the point of the cape; and, second, by the decrease in depth of the anchorage protected by the works. The closure of the gap between the breakwater and the ice-breaker is urgently reccommended, both as a check on the shoaling, and as affording a valuable increase to the protected anchorage. During the past year (1880) four vessels were driven ashore from their moorings by the sea rolling in through the gap during north-east gales, against which the ice-breaker affords no protection.

Iron Pier at Breakwater Harbour.—The report of 1879 gives a detailed account of the construction of this pier, presenting many novelties of engineering interest which may be advantageously referred to in the future prosecution of similar work. There is also an account of the appearance of some of the screw piles which were lifted (and re-set at greater lengths to meet some contingencies of soft stratum), after an exposure of five years to the action of the salt mud and water. Below the line of the bottom, the outer scale of the wrought-iron pile itself was still smooth, hard, and bright, with only a few rusty spots here and there.

From the level of the bottom up to the low water, the surface of the pile, after the mussels, which covered it to the thickness of six inches with a closely adhering coat, were scraped off, was found to be full of small cavities, and of a streaky fibrous appearance. Between low- and high-water marks the pile was still smooth; but above high-water mark to the cap, corrosion had taken place, imparting a scaly, blister-like appearance. The braces near to and above high-water mark had much corroded; the screw threads are cut perpendicular to the fibre of the iron, and nearly destroyed, making it necessary to cut them off, and weld on pieces for the new threads.

Ice-Harbours.—In ordinary years there are about three months, viz., between December 15 and March 15, during which more or less ice is running in the Delaware. This ice moves up and down stream with the tides, and from side to side of the channel, according to the direction and velocity of the wind, and at times, from repeated packing, may become heavy enough to crush in the bows of a heavy iron steamer, if they be not sufficiently guarded against it. At other times the ice may be only an inch or so in thickness, but either condition is dangerous to shipping, and especially to wooden vessels, the thin ice, from its cutting action at the water-line, being frequently more dangerous than heavier floes.

Since 1803 the general government of the United States has concerned itself in the construction and maintenance of ice-harbours on the Delaware, and there are at this time (if that at Reedy Island be counted) four of these structures in existence. Their condition may be summarised as follows:

Chester Harbour.—Practically destroyed by the projection of wharves into the sheltered space. It is recommended to abandon it to the general care of the town of Chester so soon as other works shall have been constructed.

Marcus Hook Harbour.—In good condition, affording a protected area of 600 by 250 feet, 18 feet deep at mean low water.

Newcastle Harbour.—In good condition, but needing the construction of an additional pier; affording a protected area 900 by 300 feet, 18 feet deep at mean low water.

Reedy Island Harbour.—The most important to general commerce; is almost entirely useless from decay of wooden structure and accumulation of mud. The re-establishment of a harbour at or near this point is urgently pressed by the navigation interest, with, however, a decided difference of opinion as to proper location, whether at Reedy Island or at Liston's Point, some seven miles farther down the bay. At whatever site may be determined upon, it is suggested to make the new harbour of lines of piers, formed of cast-iron hollow piles, of suitable dimensions, to be either screwed, pumped, or driven down, with diagonal braces up and down stream, horizontal braces connecting the pile heads and timber docking. The advantages of this method of construction over detached solid stone piers, such as constitute the ice-harbours of Marcus Hook and Newcastle, are that, once begun, it may be extended in almost any weather; the harbour thus constructed may be enlarged indefinitely as found desirable; and the open substructure, while it will arrest a floe of ice, offers no obstruction to tidal currents, and such a harbour will consequently be free from liability to silt up.

Improvements of the Delaware River above Philadelphia, and of the Waters of the Delaware below Philadelphia.—Numerous improvements of the Delaware river, and of the streams and inlets of the river and bay, are in progress, under the direction of the U.S. Engineers, but none of them are of sufficient importance to be classed with improvements of harbours for the convenience of nations.

R. B.

Improvement of Oswego Harbour, New York.

(Report of the Chief of Engineers U.S. Army for the year 1879, part ii., appendix HH, p. 1732, 1 pl.)

The outlet of the Oswego river into Lake Ontario was originally improved by piers on each side of the river; but at the present time breakwater works are being carried out for sheltering a considerable area in front of and at the sides of the outlet. The breakwater which is in progress starts from the shore, about 5,000 feet to the west of the mouth of the river, and after running nearly perpendicularly to the shore line for a distance of 910 feet, it turns at a slightly obtuse angle, and proceeds nearly parallel to the shore towards the direction of the river mouth. This breakwater is to be terminated opposite the west bank of the river, and, after leaving an opening of 350 feet in front of the river mouth, another breakwater is proposed to be constructed, 2,700 feet long, in a line with the other breakwater, parallel to the shore, and about 1,000 feet away from the shore line.

The western breakwater is being constructed of cribwork. Between the beginning of July 1878 and the close of that season, eight cribs had been built, of which seven were placed in position, filled with stone, and the superstructure erected, adding 250 feet to the length of the breakwater; the total finished portion being then 4,366 feet in length.

These cribs, each 35 feet square, were sunk in 21 feet depth of water, on a sandy bottom, overlying rock; and they were allowed to settle into the sand before the superstructure was erected. The exposed end was protected against the winter storms by a mound of rubble stone. Owing to delays, little progress was made till June 1879, but between then and the following October 677 feet of cribwork were sunk; and it was hoped that an extension of 700 feet would be made the following season, which would nearly complete the breakwater to its proposed length of 5,800 feet. The estimated cost of this breakwater is £232,000.

L. V. H.

Permanent Way Construction.

(Glaser's Annalen für Gewerbe und Bauwesen, 1881, p. 190.)

The Author points out that if railway extension continues to proceed at the same rate it has been doing in this century, by the end of the next two centuries the combined products of all the forests in the world will be insufficient to supply the number of wooden sleepers required in railway construction; and that therefore any truly comprehensive solution of the question must provide a substitute that will comply with all the requirements it is possible to anticipate. Iron would not only satisfy these, but also afford profitable employment to the daily increasing industrial population of the principal countries of the world. The superiority in every respect of iron over wooden sleepers is not, however, universally admitted; to prove it, three questions must be satisfactorily answered, namely, those of cost, simplicity, and safety.

As regards wooden sleepers, in the first place the best kinds of timber for sleepers are now not procurable in any appreciable quantity. The first cost and maintenance charges for wooden sleepers do not by any means show so marked a superiority over those for iron sleepers. According to Hilf's comparison between his system of longitudinal iron sleepers and wooden transverse sleepers, calculating fifty-six years as the life of the former, there is a yearly balance of 460 marks per kilometre (about £35 per mile) of line in favour of the iron sleepers, without calculating the value of the old material. The correctness of this estimate has, as far as is known, never been disputed. As regards simplicity of construction, no objection can be urged against wooden sleepers; as regards maintenance, there are many serious ones, involving safety to traffic, careful inspection, and labour in repairs.

Safety is endangered by the difficulty of keeping the line to gauge, owing to the imperfect hold the sleepers exert on the spikes, which is due to the variable holding properties of timber under different conditions, and the gradual destruction of the fibre from the blows transmitted through the foot of the rail during the passage of trains. A want of uniform rigidity of the road, due to the different ages of the sleepers produces conditions which seriously injure the rolling stock. The use of wooden sleepers does not recommend itself on the ground of cost and safety to traffic. Next the question of iron tranverse sleepers demands attention; the advantages claimed for them are simplicity in construction and renewals, rigid maintenance of gauge, simplicity of drainage, durability, and handiness in time of war. The first cost, and cost of laying of both transverse and longitudinal iron sleepers is about the same. As regards maintenance, sufficient data are not procurable for a correct comparison, but it is presumable that with good ballast the more equal distribution of the load on a longitudinal sleeper road would reduce the cost of maintenance.

Simplicity of construction is claimed for the transverse sleepers, on the grounds of greater handiness of the parts; but then, again, the fact that one longitudinal is equal to four tranverse sleepers should not be lost sight of. In laying curves, the longitudinal system certainly requires greater care and precision, and the work of renewing is more complicated; in time of war this is an acknowledged defect. A superiority in respect of maintenance of gauge is claimed for the transverse, but it is no less obtainable in the longitudinal system as exemplified in the Berlin municipal, Hilf, and Rhenish railway permanent way.

A decided objection to iron transverse sleepers is, that they do not afford the same hold on the ballast the heavier wooden ones do; that they require to be bent in order to give the proper cant to the rails, and in consequence are always liable to revert to their normal condition. Again, the fracture of a rail on a cross-sleeper system is attended with far more serious consequences than could possibly occur with the longitudinal system.

Longitudinal sleepers were the first made use of; transverse were not introduced until 1876. Even in the earliest times the following requirements were recognised as requisite for a perfect system of superstructure; (1) a head of a section sufficient to resist the wear; (2) a web deep enough to carry the weight; (3) a base sufficiently broad to distribute the load on the ballast. These conditions are perfectly realised by the longitudinal system alone, the best examples of which are furnished by Hilf, Haarmann, and the Rhenish railway.

The Author then proceeds to discuss the relative advantages and disadvantages of the Hilf, Haarmann, and Rhenish railway permanent way, to enumerate the evident objections to every system of transverse sleepers, and to combat and answer all objections to longitudinal sleepers, referring to the absolute necessity of greater attention being paid to the conditions of safety of a line in consequence of the growing desire for an increased rate of speed, which likewise demands heavier engines, and these again introduce further elements of danger to the permanent way, straining it more severely and rendering cases of derailment more frequent and more serious.

A serious accident which occurred on the Cologne-Minden railway shortly after the speed on that line had been experimentally increased, drew attention to the subject and led to a series of experiments as to the resistance offered by the various types of permanent way to the forces exerted by the rocking of a heavy engine. This also appeared a good opportunity for testing the relative efficiency of the various descriptions of permanent way. But the results of these experiments, however interesting, were not of a character to afford any practical solution of the question, as the actual conditions of the case were not correctly reproduced. Accordingly another plan was adopted, viz., an ordinary railway wagon (tare 4,500 kilogrammes), loaded with 17,500 kilogrammes of iron, was provided with a gallows, from which was suspended by a chain 5 metres in length a block of cast iron weighing 228½ kilogrammes, at a distance of 1·75 metres (wheel base of the Cologne-Minden locomotives) from the loaded axle. This weight, with a swing of 3 metres (equal to a vertical fall of 1 metre), was made to strike the inner side of the rail, the results of which are given in the four Tables appended to the Paper, and were registered by means of a lump of clay resting against the outer edge of the rail.

The apparatus and weights made use of in these experiments more than satisfy the conditions it was sought to reproduce, and afford a reliable test of the capacity of the various systems to resist the effects of the rocking of a heavy locomotive; the results are unfavourable to the system of transverse sleepers, but prove that a well-constructed permanent way with longitudinal sleepers is capable of providing perfect security in this respect.

The Author's own comments on the behaviour of the different types experimented on, and his deductions therefrom, are given in full, and conclude with a remark that though the behaviour of permanent way in presence of such horizontal forces is certainly not alone conclusive as to the value of any one system, since many other questions must necessarily also enter into the determination, yet the results of these experiments go a long way towards a solution of the question in favour of the use of longitudinal sleepers.

W. A. B.

Tire Fractures on German Railways.

(Glaser's Annalen für Gewerbe und Bauwesen, 1881, p. 186.)

The period under consideration extended from the 1st October, 1879, to the 31st March, 1880. The particulars are furnished by a statistical report issued by the Imperial railway department. Forty-five administrations, working 20,080 miles of open line, reported 5,039 fractures to tires, whilst ten administrations, with 270 miles, did not report a single one. The average number per 100 kilometres (62½ miles) of line was 15·57, the highest being 46·58, the lowest 1·47.

The number of accidents (253) reported for October suddenly increased in December to 2,175, and then gradually decreased, the maximum number occurring on the 9th, 10th, 17th, and 23rd December. 31·3 per cent. occurred at temperatures varying from 32° to 43° Fahrenheit, 18·9 per cent. above 32°, 4·1 at 32°, 77·0 below 32°. 54·9 per cent. occurred on goods trains, 40·1 per cent. on passenger, and 5·0 on empty trains.

The description of permanent way and ballast is not particularised by all, though the Bavarian State railway, which also does not supply this information, reports that all its accidents occurred on the 3,921 kilometres of its road that is laid with transverse sleepers.

Under the head "Description of Vehicle," the accidents are as follows:—"Open goods" show 33·3 per cent.; locomotives and tenders 31·6; "covered goods" 18·0; passenger 12·4; passengers' luggage vans 3·5; post-office vans 1·8 per cent. It is a remarkable fact that these statistics do not show a uniform proportion between the fractures to tires of engines and those to tenders; on some lines more of the former and less of the latter occurred, and on others about an equal number of each. Out of 3,269 fractures to cast-steel tires, unclassified cast steel showed 220; Tiegels, 1,572; Bessemer, 16; Martin, 28; and manganised, 1,433 defects. Again, out of 1,054 fractures, 889 occurred to tires of puddle steel, 57 to tires of close-grained iron, and 108 to iron (unclassified) tires. On the whole, though the data are not so complete as they might be, it may be assumed that puddle steel and wrought iron, owing to the circumstances of their manufacture, possess more useful qualities, and are less liable to sudden fracture than cast steel, though they do not stand as much wear.

For the period under review, the proportion of damaged cast-steel disks to fractured tires is as 2 : 9, a less favourable result than that previously reported, viz., as 1 : 7.

Screw-head fastenings furnish by far the greater number of accidents, though from the report it is not apparent that this was due to defects in the fastenings themselves alone.

Under the head "Description of Tire-fastenings," among those of older types, 59·4 per cent. occurred to screw-head fastenings; 4·9 to through screw-bolt fastenings (conical); 17·1 to through screw-bolt (cylindrical); 11·9 to screw-fastenings (unclassified); 3·3 to stud-bolt; and 0·7 to riveted fastenings. Among those of later types, 0·5 per cent. occurred to the Mansell ring, 2·0 to Kaselowsky's patent fastenings.

Only a few reports mention whether the fractures were longitudinal or transverse; 73·3 per cent. were total, 26·7 partial fractures. 910 occurred in transit, 327 in the workshop (whilst being turned up), 199 at crossings, 178 on curves, 60 while shunting, and 644 were detected on examination at stations. Premiums to carriage examiners greatly contributed to the early detection of flaws, &c.

As regards dimensions, those tires between 1·22 inch and 1·57 inch afford the greater number of defects. Tires three times turned up contribute the greatest number of cases of fracture, whilst those untouched afford as many as those that had been re-turned as often as seven times. 23·7 per cent. of the total number of damaged tires were from six to eight years old, whilst 9·4 per cent. only were from twelve to twenty-four years in use.

Information as to "distance run" is so imperfect that a comparison in this important respect is impossible. Opinions as to the cause of fracture are not generally afforded, though frequently it is attributed to the effect of the unusually great variation of temperature, to unequal heating from excessive pressure of brakes, to old flaws and fractures, and to faulty welds, &c. Of great interest is the result of experiments made by the Bavarian State railway on the strength and tenacity of some broken tires; the average results of twenty-three experiments are as follows:—

(*a*) Tensile strength = 6,300 kilograms per square centimetre (40 tons per square inch).

(*b*) Reduction in sectional area, after breakage, 21·4 per cent. of original area.

(*c*) Ultimate extension, after breakage, 12·2 per cent. of the original length.

W. A. B.

Tire Fastenings.

(Glaser's Annalen für Gewerbe und Bauwesen, 1881, p. 453.)

The characteristic feature of the system described in this Paper, which is illustrated by a series of seven diagrams, is the shrinking on of the tire, the skeleton of which is dovetailed on the one side; and in the other, a triangular groove cut in the rim receives a segmental rolled iron ring of a peculiar section, 600 to 900 millimetres in length which also fits into a similar groove in the inside face of the tire. This iron ring, in segments, is, while at a red heat, hammered into the grooves in the skeleton and tire, and effects between them so close a union that a separation of the two, even in the event of the fracture of the tire, is practically impossible; any movement also of the tire on the skeleton is effectually prevented.

The special feature of this invention is the simple and ingenious method employed to secure the ends of each segment of the ring separately, by a modification of the section of the groove in the rim of the skeleton.

The cost of applying this method of tire-fastening per axle, is as follows:—

	s.	*d.*
1. Labour of turning grooves	6	0
2. „ in fixing ring, &c.	3	6
3. Workshop charges and cost of material	3	7
Total per axle	13	1

In the case of engine and brake wheels four screws are recommended in each wheel, so that to the cost as above given 8*s.* per axle must be added for wheels of that description, each screw being calculated to cost 1*s.*

In order to test the efficiency of this system of fastening tires by means of a wrought-iron ring welded into the skeleton and the tire, experiments were made, the results of which showed that a force of 175,000 kilogrammes per lineal metre was necessary to separate the tire from the skeleton. In the event of the tire being fractured, it is therefore evident that it could not fly off the skeleton. Further, as compared with other fastenings, the results were most satisfactory.

W. A. B.

The Wootten Locomotive Engine. By J. S. Bell.

(Journal of the Franklin Institute, May 1881, p. 340.)

Mr. J. E. Wootten, of the Philadelphia and Reading railroad, has designed and constructed a locomotive boiler for the combustion of anthracite and lignite, though specially for the utilisation, as fuel, of the waste produced in the mining and preparation of anthracite coal, amounting to from 20 to 25 per cent. of the output of the mines of Pennsylvania. The special feature of the engine is the fire-box, which is made of great length and great breadth, extending clear over the wheels, giving an area of from 64 square feet to 76 square feet. The draught, diffused over so large an area, is so gentle as not to lift the fine particles of the fuel. The system is available for both passenger traffic and freight traffic, and there are now seventy-five such engines in use on the Reading and other roads having access to the anthracitic region.

A number of express engines of this type of boiler are engaged on the fast trains between Philadelphia and Bound Brook. The fire-box shell is 8 feet 8 inches wide, and 10 feet 5 inches long; the fire-box is 9½ feet by 8 feet, making the grate-area 76 square feet. The grate is composed of bars and water-tubes alternated. The height of the fire-box is only about 2 feet 5 inches above the grate. The grate is terminated by a bridge of firebrick, beyond which a combustion chamber, 27 inches long, leads to the flue-tubes, one hundred and eighty-four in number, and 2 inches in diameter. The fire-box is stayed to the shell above by screwed stay-bolts. The cylinders are 21 inches in diameter, with a stroke of 22 inches; the four-coupled driving wheels are 5 feet 8 inches in diameter. The engine weighs 44 tons, of which 29 tons are placed on the driving wheels. The heating surface of the furnace is 135 square feet; that of the flue-tubes is 982 square feet; together 1,117 square feet, equal to 14·7 times the grate-area. Hauling fifteen passenger-cars, weighing, with passengers, 360 tons, at an average speed of 42 miles per hour, over ruling gradients of 1 in 89, the engine consumed 62 lbs. of fuel per mile, equivalent to 34¼ lbs. per square foot of grate per hour.

In comparing by trial a freight-engine of the Wootten type, with an ordinary Consolidation engine, the following average results were obtained, in running trips of 110½ miles:—

	Ordinary.	Wootten.
Coal consumed per mile run	97½ lbs.	73 lbs.
Water evaporated per lb. of coal . .	6·61 lbs.	8·93 lbs.

There is an exemption from emission of sparks and cinders at the chimney, due to the mildness of the draught.

D. K. C.

Economy in Firing Locomotives.

(Glaser's Annalen für Gewerbe und Bauwesen, 1881, p. 431.)

The Author, after dwelling on the importance of the subject, the attention directed to it by the Prussian Government, and the experiments made, points out the unsatisfactory nature of the results hitherto obtained, and goes on to describe the waste, danger, and inconvenience attendant on the imperfect combustion of fuel. Smoke and spark-flying are the bugbears of all engine drivers. Smoke inconveniences and annoys the travelling public, hinders the free view of the track, and so introduces an element of danger to traffic. Sparks are a source of danger to rolling-stock, goods, and the country generally, as they are apt to set fire to grass, forests, &c., entailing compensation for damages on the railway authorities. The appliances hitherto provided have failed to obviate all the inconveniences complained of, the Belpaire system not excepted.

To remedy the state of affairs, and to provide for the perfect utilisation of all the products of combustion, and to prevent sparks flying, Herr Nepilly supplies a fire-grate with a novel arrangement of bars, which admits through an open grating in the front part of the fire-box a supply of air amply sufficient to support perfect combustion, while a fire-bridge of peculiar construction, attached to the tube-plate below the tubes, breaks the force of the strong draught entering from the front, and prevents the smaller particles of coal from being carried away.

The arrangement consists principally of the following :—

(1.) A cast-iron fire-grate in two portions, the fire-bars in each being of different dimensions, one fixed with a certain amount of inclination forward, the other horizontal. The space between the fire-bars of each portion vary considerably. In the portion nearest the fire-door, which is inclined forward, and occupies about two-thirds of the whole grate-surface, the fire-bars are 0·35 inch in width and 0·11 inch, or at most 0·15 inch apart. In the set next the tube-plate, the fire-bars are 0·315 inch in width and 0·315 inch apart, and are laid horizontally. This portion of the grate is also so constructed as to admit of its being lowered from the foot-plate in order to get rid of slack, &c., when in motion.

(2.) Between the last-mentioned and the tube-plate there is a space of about 3 inches, which is occupied by a vertical cast-iron grating about 8 inches in height, the upper portion of which is bent over to meet the tube-plate.

(3.) A peculiarly constructed fire-bridge, consisting of an iron frame carrying a number of fire-bricks so shaped as to form a succession of transverse arches across the fire-box. It is fixed on to the tube-plate below the tubes, so as to leave above and between it and the fire-box cover a sectional area which must not exceed the sum of the sectional areas of the tubes.

The process of firing is as follows:—

The fuel deposited on the sloping and closely compacted set of fire-bars is first thoroughly well roasted, in consequence of the limited supply of air it receives, and the gases it contains are gradually expelled; meanwhile it slowly works its way forward, by virtue of the inclination at which the fire-bars are fixed, until it arrives upon the front set of widespread bars, where in consequence of the abundant supply of air it now receives from above and below, a very rapid disengagement of heat takes place.

The temperature of the air entering through the vertical grating is rendered so intense by the excessive heat of this fire, and by the glowing surface of the fire-bridge above, that, as the result shows, the gases liberated from the coal roasting on the inclined portion of the fire-grate are entirely consumed.

The draught is also so efficient that the diameter of the exhaust or blast-pipe of passenger engines of the Prussian type has been increased 0·4 inch without in the least reducing the supply of steam, and the violence of the blast has been thus so reduced that the particles of small coal remain undisturbed, and all spark-flying prevented. Again, the motion of the locomotive is freer in consequence of the increased facility for the escape of the exhaust steam from the back of the piston and consequent reduction of the resistance offered by it, an advantage that cannot be too much dwelt on.

The saving effected by this system is equal to about £60 per engine per annum, while the first cost of fitting up an engine with this arrangement is about £25, including bricks for the fire-bridge, which cost about £1 5*s*., and have to be renewed every four or five months.

Considering the satisfactory results obtained, the Nepilly system may be regarded as a considerable advance towards perfect economy in fuel, and one that will, in the Author's opinion, be soon extensively introduced on all continental railways.

W. A. B.

Milan Gorgonzola and Vaprio Steam Tramway.

[Professor Clericetti, of Milan, having had the kindness to present a copy of the directors' and engineer's reports on the first eighteen months' working of this tramway, which he considers one of the best organised, the following particulars are extracted as of more immediate professional interest in regard to the present position of such undertakings in Italy.]

The length of the line is about 18¾ miles. It is laid with Vignoles rails of Bessemer steel, which were procured at £8 8*s*. per ton from the Gutehoffnungshütte Works at Oberhausen, Rhenish Prussia. The laying, paving, &c., was all done by Messrs. Mereghetti and Arnaboldi, at the cost of 4*s*. per lineal yard; in spite of bad weather and constant use, the work has stood well from the first, and will last long without any heavy repairs. The rolling stock comprises nine locomotives and twenty-nine cars; of the latter nineteen are closed, and ten are open cars for summer traffic only. The engines are of various patterns, having been built by Brown, of Winterthur; Krauss, of Munich; Fox Walker and Co., of Bristol; Henschel, of Cassel; and two by Cerimedo and Co., of Milan. The cars were built in Neuhausen, Paris, and Philadelphia, and by F. Grondona in Milan. Between the terminal stations at Milan and Vaprio there are seven intermediate stopping places, dividing the entire distance into eight stages, for each of which a uniform fare is charged of 2½*d.* first class and 1½*d.* second. The trains do not stop anywhere else on the line. In new first-class cars, reserved compartments at extra fare have lately been introduced. The line is under the supervision of the Government Railway Commissioner, by whom it is frequently inspected, the engines tried, and the drivers certificated after passing an examination. Goods traffic is not yet developed to any considerable extent, the gross proceeds from this branch not having exceeded £285 in the first eighteen months. In consideration of permission to work the line with locomotives, postal service is performed for the sum of £100 per annum. The water-tank at Vaprio terminus, for supplying the engines, is filled from a well by a steam-pump, which is worked with steam from the locomotives themselves while they are taking in water. At the Milan terminus—in addition to the usual offices, waiting rooms, engine and carriage sheds, water-tank with steam-pump, stores for coal &c.—there is also a repairing shop, where all repairs are executed, besides various other work, as recommended at the outset by the engineer, Signor Enrico Radice. The locomotive repairs have included renewals of tyres, connecting-rods, valve-rod links, crank-pins, eccentrics, piston-packing springs; substitution of laminated bearing springs for original spiral springs; renewal of firebox, alteration of valve-chests and feed-pump, and removal of regulator from smoke-box to steam-dome.

For the eighteen months from the opening of the line in June 1878 to the end of 1879, comprising 567 days of running, the total train-mileage was 151,157 miles, with an average consumption of 8·430 lbs. coal, 0·156 lb. oil, and 0·085 lb. firewood per mile. The total locomotive expenses were £5,546, or 8·73*d.* per train-mile: comprising coal £1,250, firewood £118, together £1,368, or 2·15*d.* per train-mile; oil for engines and carriages, 0·75*d.*; cotton-waste and cleaning cloths, 0·08*d.*; wages of foremen, guards, drivers, and firemen, 2·93*d.*; engine and carriage lamps, 0·06*d.*; repairs, cleaning, and shunting, with all shop expenses, materials, and wages, 2·59*d.*; and water supply, 0·17*d.* per train-mile, in consequence of water having had to be brought from the distant canal at Vaprio at a cost of about 5*s.* 6*d.* per day during the eleven months previous to the completion of the well at that station. The total receipts, of which £17,288 were from passenger fares and goods, amounted to £17,939 for the eighteen months to the end of 1879, and the total working expenses to £13,851; leaving a profit of £4,088 on the fully-paid capital of £40,000. Of the profits, 5 per cent. is carried to a reserve fund. The entire staff comprises sixty-eight persons.

A. B.

Steam Traction on the Hamburg Tramway.

(Deutsche Bauzeitung, 1881, No. 40, p. 235.)

In 1878 the Hamburg Tramways Company made an extended series of experiments with engines by Samuelson, Hughes & Co., a "Rowan" engine by Kitson, and a "Brown" engine by the Swiss Locomotive Company of Winterthur. Of these engines Brown's system was adopted, and a second similar engine was ordered, and in the year 1878 the two engines ran 2,700 double journeys over a line 6·92 kilometres (4·3 miles) long.

After this experience the company applied for leave to gradually extend the use of locomotives on their lines, and this request was granted by the authorities, who drew up a series of regulations to be conformed to by the company. Amongst other matters the regulations stipulate that not more than two cars be coupled to the engine; that a speed in the city of 12 kilometres (7½ miles), and outside of 16 kilometres (10 miles) per hour shall not be exceeded; speed is to be reduced at crossings and similar places; the discharge of steam from the chimney is only occasionally permitted when absolutely necessary, and only then in the more unfrequented streets—in certain named streets this is absolutely forbidden; firing during a run is only exceptionally allowed, and filling up and blowing off only at end stations. The concession applies to "Brown" engines only; for the trial of other systems special permission must be obtained.

In 1879 the engines made 1,093 double journeys with one car, and 2,985 with two cars, and in 1881 the numbers had increased to 2,656 double journeys with one car, and 9,153 with two cars, being about one-third of the whole number made by horse and steam-power.

The company have published no statement of the comparative cost of horse and steam traction, from which is to be inferred that the result is as yet not very decided either way. The company have at present four "Brown" engines in work and one in reserve; they have also procured, for experimental purposes, a Samuelson combined engine and car, and an engine by Krauss and Company, of Munich. Accidents and difficulties arising from the use of steam in the streets have been very few, and, although horses shied generally at first, they have long become accustomed to the engines.

W. P.

The Perkins Machinery of the Steam Yacht "Anthracite."[1]

By Chief-Engineer ISHERWOOD, U.S. Navy.

(Journal of the Franklin Institute, January, February, March, 1881.)

This Paper is an analytical study of the report of Mr. F. J. Bramwell to the Directors of the Perkins Engine Company, and the report of a Board of Chief Engineers of the United States Navy, both reports having been written last year.

The engine is vertical, direct-acting, and inverted, and consists of three cylinders compounded, of which the first and second are single-acting, one above the other, and the third is double-acting, alongside the second cylinder. The cylinders are successively 7¾ inches, $15\frac{3}{16}$ inches, and $22\frac{13}{16}$ inches in diameter, having net areas as 1, 4·26, and 17·20, in which the area of the 3rd cylinder is counted twice, since the piston is double-acting.

Steam from the boiler is admitted to the upper end of the 1st cylinder, thence exhausted to the lower end of the 2nd cylinder, thence to an intermediate receiver, and thence to the 3rd cylinder. The interspace between the 1st and 2nd pistons is open to the receiver. The total clearance-spaces are respectively 21 per cent., 19 per cent., and 9 per cent., of the 1st, 2nd, and 3rd cylinders.

The metal of the cylinders is 1½ inch in thickness, and embedded in it is a coil of steam-pipe ⅝-inch in diameter outside and ⅜ inch inside, designed to act as a steam-jacket, in the top and bottom as well as in the walls. The surface-condenser consists of galvanised wrought-iron tubes in pairs, one within the other, the water being forced up the inner tubes and downwards in the annular space, the steam being condensed on the outer surface of the outer tubes, which amounts to 422 square feet.

The boiler is composed entirely of water-tubes enclosed in a sheet-iron double-shell, 4 inches thick, filled with vegetable-black as a non-conductor. The shell is 5 feet 3 inches long and 4 feet 10½ inches wide externally, and 9 feet 2 inches high. The tubes are of iron, 3 inches in diameter outside and 2¼ inches inside. The grate is 45¾ inches wide and 49 inches long, and has an area of 15·32 square feet. It is surrounded by a parallelogram of tubes in eight tiers, forming the firebox; and above these the tubes, 140 in number, are placed in close order, in ten tiers, surmounted by a 4-inch steam-collecting tube ½ inch thick. All the tubes are surrounded by the gases of combustion, so that the six upper rows of tubes occupied by steam act as superheating tubes, making up 11 cubic feet of steam room, with 10·11 cubic feet of water-room. The water-heating surface of the tubes was, externally, 300¼ square feet, or internally, 225½ square feet. The steam superheating surface was, externally, 325·9 square feet, or, internally, 239·20 square feet. The exterior water-heating surface was 19·6 times the grate-area; the interior surface was 14·72 times.

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[1] Further information concerning the "Anthracite" will be found in the library of the Inst. C.E. under the title "Three Official Reports on the working of the Perkins' system of Engines and Boilers, &c. &c." 8vo. London, 1881.

The engine and boiler were tried in the New York navy yard, August 13 and 14, 1880, the vessel having been moored to the wharf. The trial lasted twenty-three hours fifty-eight minutes, commencing with a clear fire and ending with the same. Cumberland coal, semi-bituminous, discharging 17·6 per cent. of ash and clinker, was used. The cylinders were tested and found tight. The throttle-valve was maintained wide open. The average results were as follows: The steam was cut off at 52 per cent. of the stroke in the 1st cylinder, and at 28⅓ per cent. in the 3rd cylinder, having been expanded, in all, 25·7 times. There was not any cushioning of the steam. The back pressure in the condenser was 1·61 lbs. per square inch absolutely; the vacuum was 26¾ inches of mercury, and the barometer stood at 30·02 inches. The pistons made 103·03 double strokes per minute, giving 257 feet per minute speed of piston. The absolute initial pressure in the 1st cylinder was 201·64 lbs. per square inch, in the 2nd cylinder 60 lbs., and in the 3rd cylinder 27·71 lbs. The net indicator horsepower was, for the 1st cylinder, 20·06 HP.; for the 2nd, 6·34 HP.; for the 3rd, 33·12 HP.; together, 59·52 HP. The feed-water was consumed at the rate of 24·61 lbs. per indicator HP.; and at the rate of 9·27 lbs. from and at 212° Fahr. per pound of coal, or of 11¼ lbs. per pound of combustible. The coal was consumed at the rate of 11·99 lbs. per square foot of grate per hour, and of 3·08 lbs. per indicator HP. The temperature in the chimney was 700° Fahr.

The weight of steam indicated at the point of cut-off in the 1st cylinder was only 42¼ per cent. of the weight of water vaporised from the boiler; at the end of the stroke in the 2nd cylinder the weight of steam indicated was 61·6 per cent.; and in the 3rd cylinder 90 per cent. These proportions prove that the steam was condensed within the cylinders in large proportions. Of this condensation there was sensible evidence when the indicator-cocks of the 1st and 2nd cylinders were opened, water flowing freely from them.

In analysing the experiments made by Mr. Bramwell on the machinery whilst the vessel was under way, on the 22nd May, 1880, Mr. Isherwood has made estimates of the quantity of feed-water and coal consumed during the trial for a period of eleven hours ten minutes. The coal used was Nixon's Navigation, which has 5 per cent. of refuse. The steam was cut off in the 1st cylinder at 49 per cent. of the stroke, and was expanded altogether 26·9 times. The coal was consumed at the rate of 9·02 lbs. per square foot of grate per hour. The absolute initial pressure in the 1st cylinder was 205 lbs. per square inch. The pistons made 130·4 double-strokes per minute, making a speed of 326 feet of piston per minute. The net horse-power developed in the 1st cylinder was 28·55 HP.; in the 2nd cylinder, 12·79 HP.; in the 3rd cylinder, 29·03 HP.; together, 70·37 HP. The coal consumed per HP. was 1·96 lbs. per hour; the water was consumed at the rate of 20·45 lbs. per HP., and evaporated at the rate of 12·11 lbs. from and at 212° Fahr. per pound of coal.

The remarkable difference of economical performance between the two trials—showing, in the first case, a consumption of 3·08 lbs. of coal per HP. per hour, and, in the second case, a consumption of 1·96 lb.—is accounted for, in the first place, by the less proportion of steam condensed in the cylinders in the second case. The proportions were respectively 56·76 per cent. and 31·27 per cent. at the point of cut-off in the 1st cylinder; and at the end of the stroke of the 3rd cylinder they were 10 per cent. and 8½ per cent. These differences are ascribed to the relatively greater degree of superheating and wire-drawing of the steam in the second case; also to the higher speed of pistons, and to the superiority of the coal used in this case.

Mr. Isherwood considers that "it is of the greatest importance to mankind that there shall be discovered the pressure of steam, the measure of expansion, and the degree of superheating which will produce the highest economical results from the fuel, without prejudice to the durability and reliability of the machinery, and without requiring exceptional care and skill in its management. The attempt made to solve this problem by the construction of the machinery of the "Anthracite" is in the right direction and most praiseworthy; and it will be a subject of lasting regret should a series of exhaustive experiments be not made with it."

D. K. C.

Experiments on the Otto Gas-Engine.

By Prof. Francesco Sinigaglia.

(L'Ingegneria civile e le Arti Industriali, vol. vii., p. 56.)

This Paper consists in a mathematical investigation of a large number of indicator diagrams, sixteen of which are reproduced for reference. The diagrams are of two kinds; the first refer to the results obtained from the explosion of the mixture of gas and ordinary air, which may be called diagrams of motor power; the second kind are obtained when the valve which admits the gas is closed, and are called diagrams of resistance. The various stages of pressure are clearly represented by the diagrams, from which it appears that at the end of the motor stroke the internal pressure in the cylinder is less than that of the atmosphere. The highest pressure figured on any of the diagrams is 7 atmospheres. The Author remarks that the machine is liable to become dirty internally, and should be frequently overhauled and cleaned. The editor of the journal adds in a note that if oil of a good quality is employed for lubrication it is sufficient for the valve to be cleaned every twelve or fifteen days, and the interior of the cylinder once a month. From a great number of diagrams the Author deduces the following formulæ:—

Let A = the area of piston in square centimetres, which = 103·81.
C = the length of stroke in metres, which = 0·2315.
p_m = the mean pressure, taken from the diagrams.
n = the number of strokes per second.

Then the work is thus represented—

$$\frac{n\,p_m\,A\,C}{2 \times 60} \text{ kilogrammetres per second.}$$

The Author proceeds to give formulæ, too complicated for abstract, for the resistance of the machines, for proportion between the gas consumed and the air admitted, for the heat produced by the combustion, for the heat conducted away by the products of combustion, for the relation between these two last-mentioned quantities, for the relation between the heat developed and that absorbed by the water, for the heat lost by vaporisation of water and by radiation, and for the proportion between the work indicated by the diagrams, and that actually utilised as motor power. He finally arrives at the result that the indicated work, where $n = 170$, and $p_m = 1{\cdot}590$, amounts to 0·722 HP.; the friction to 0·283 HP.; and the effective work to 0·439 HP., or 60 per cent. of useful effect.

The consumption of gas per HP. indicated per hour he gives as—

$$\frac{0{\cdot}960 \text{ cubic metre}}{0{\cdot}734 \text{ HP.}} = 1{\cdot}307 \text{ cubic metre,}$$

and per HP. effective as

$$\frac{0{\cdot}960 \text{ cubic metre}}{0{\cdot}451 \text{ HP.}} = 2{\cdot}128 \text{ cubic metres.}$$

The editor adds a note to the effect that a consumption of 1·200 cubic metres per HP. per hour is the highest that has yet been determined from numerous experiments conducted by very able engineers for any of these engines.

The Author concludes that the diagrams derived from his practice differ from those drawn according to theory, those drawn according to Boyle's law of compression being 20 per cent. in excess of, and those drawn according to the adiabatic theory being 20 per cent. less than, those which he has obtained. The cost of gas, at the price of 32 centissimi per cubic metre (without allowing anything for the hire of meter), is 3·60 lire (2*s.* 10½*d.*) for a day of ten hours, which he states to be much higher than that of a steam engine of equal power, that is to say, of 0·451 effective HP.

F. R. C.

On Girard Turbines. By J. C. BERNARD LEHMANN.

(Zeitschrift des Vereines deutscher Ingenieure, vol. xxv., p. 258.)

The present Paper was written with the object of defending Girard turbines against some adverse criticisms by Professor Fink in the 'Civilingenieur.'

Girard turbines belong to that class of parallel-flow turbines in which the jet velocity is equal to that due to the whole head; the essential condition of the Girard construction is, however, that the stream must be able to pass through the buckets in such an unconfined manner that its cross-section is not compelled to conform to that of the bucket; consequently the condition that the relative velocity of flow, multiplied by the sectional area of the bucket, equals a constant, no longer holds good as in turbines in which the buckets are completely filled. The method usually followed is to strike out the curve of the bucket on the development of a cylinder whose diameter is the mean diameter of the jet; the Author considers that the unconstrained action of the water is better secured by shaping the buckets so that a plane passing through the centre of the jet at entrance, and tangential to the above cylinder, shall intersect the bucket in the correct curve. To enable the stream to spread out sideways as much as it requires, the wheel must also be bell-mouthed downwards, and practical experience shows that if the width of the buckets on the outlet side is made from 2½ to 3 times that on the inlet side, the enlargement is ample.

The proper ventilation of the wheel is another point to be carefully attended to, otherwise the water tends to hang in the buckets as they pass under those jet orifices which are temporarily closed by the regulating gear, and a considerable loss of efficiency results.

The general conclusions summarised by the Author at the end of his Paper are, that deductions based on the theory of closed stream turbines, in which the velocities are functions of the bucket section, are for the Girard turbine inadmissible, but that the theoretical efficiency of both classes is the same. He considers that the practical efficiency of the Girard open-stream turbine may be greater in consequence of the reduced skin friction in the buckets.

The application of Girard turbines is therefore to be recommended in those cases where, with a variable supply of water and no tendency in the tail water to rise, the highest efficiency is desired.

The Author remarks that his deductions are amply verified by the extended use of the turbines, during the last fifteen years, with the most satisfactory results.

W. P.

Friction of Lubricating Oils. By C. J. Woodbury.

(Transactions of the American Society of Mechanical Engineers, 1880.)

In the construction of an apparatus capable of measuring the friction of oils, it is necessary that the temperature, velocity, pressure, frictional area, thickness of film of oil, and the mechanical effect of the friction, should be constant. The radiation of heat should be reduced to a minimum, and no part of the oil should escape until subjected to attrition. In the apparatus designed and employed by Mr. Woodbury, an annular disk of hardened tool-steel, fastened on an upright shaft, revolves under a hard-bronze disk. The lubricating oil is tested between these disks, and the resistance is measured by means of a dynamometer. The coefficient of friction, under a pressure of 5 lbs. per square inch, at the temperature 100° Fahrenheit and a speed of five hundred revolutions per minute, varied from 9½ per cent. for sperm oil to 24¼ per cent. for neat's-foot oil, in a collection of thirty-five samples. With castor oil, the friction was so great as to dismount the driving band.

The resistance varies very much with the temperature. For sperm oil it varies from 24·05 per cent. at 50° Fahrenheit, to 7·11 per cent. at 130° Fahrenheit, under a pressure of 5 lbs. per square inch and a speed of 513 feet per minute. There is a lard oil which gives 28 per cent. of friction at 72° Fahrenheit, and 16¾ per cent. at 130° Fahrenheit, at a velocity of 564 feet per minute.

The resistance of oil under different pressures increases at a much less ratio than the pressure. At a temperature of 80° Fahrenheit, for instance, at a speed of five hundred revolutions per minute, under pressures of 1 lb., 2 lbs., 3 lbs., 4 lbs., and 5 lbs. per square inch, the corresponding resistances at the dynamometer were 3½ lbs., 5 lbs., 6·1 lbs., 7·17 lbs., and 8 lbs.

Mr. Thurston, in discussion, renews the caution given by Mr. Woodbury, that the results of his experiments, which represent the relative value of oils for mill-spindles, are not to be taken as representing the relative values of the same oils for the lubrication of crank-pins or steam-cylinders, where the temperatures and pressures are far in excess of those to which mill-spindles are subject.

There are many valuable diagrams and tables in the Paper.

D. K. C.

On the Use of Iron Framing for Levels in Coal Mines.

By Rudolf Eichelter.

(Zeitschrift des Berg- und Hüttenmännischen Vereines für Steiermark und Kärnten, vol. xiii., p. 9.)

This Paper describes the method adopted for securing a main drawing level at the coal mine of Oistro. The seam, 32 metres

(105 feet) thick is inverted, having a reversed northerly dip of 55 to 75°, the apparent roof being a tertiary blue clay, which is covered by the Gailthal slates of paleozoic age. The portion of the seam under work, about 500 metres long, is laid open by two levels 40 metres (43 yards) vertically apart; and in order to facilitate the rapid removal of the pillars, it was necessary to drive a new main haulage level in the adjacent clay bed. This was done in spite of the enormous pressure developed by the swelling of the ground, in preference to driving it in the coal, to guard against the chances of spontaneous ignition. As the quantity of coal was computed to be sufficient for eight years' working, the question was as to the cheapest method of keeping open the levels and inclined planes for that period. Three methods were considered, namely, timbering, walling, and iron framing. As regards the first, it was found from the experience of an upper level driven in the same clay, and secured with frames of pine timber 12 to 16 inches square, and averaging 20 inches apart, that the entire timbering required renewal at least four times in two and a half years, which gives, for the required period of eight years, a total cost of £5 2*s.* 6*d.* per lineal metre, assuming the present price of wood, of 10*s.* per cubic metre, to be unaltered for the whole period. The cost of brick walling, 12 inches thick, was computed at £3 14*s.* 6*d.*, or, with accumulated interest, £5 5*s.* 3*d.* per metre. The third method, or that with wrought iron instead of timber frames, was computed to be considerably cheaper than either of the preceding—or, including interest, without deducting the returned value of the old iron, at £4 6*s.* per metre—and has therefore been adopted. The frames are of the ordinary rectangular post and lintel construction; the former 7½ feet, and the latter 6 feet long, and are made of H-iron, 5 inches high, 2¾ inches breadth of flange, and 0·27 inch thickness of web, weighing 32½ lbs. per yard. This, although less advantageous as regards strength than an elliptical section of gallery, was preferred, as requiring a simpler and less expensively fitted ironwork. The two uprights are fixed in a floor or sill piece of oak, 8 inches square; and the cap, to which two angle-irons, 2·3 inches in the side, are riveted at the distance of 6 feet apart, is placed across their upper ends. The thrust of the walls forces the uprights against the projecting angle-irons, and binds the pieces together without any special fastening. Every second frame has the cap piece strutted by a Λ strut made of an old mine rail, whose ends are supported on angle-iron brackets riveted to the uprights, 25½ inches from the top.

At first the frames were placed 30 inches apart, but the pressure was so great that the distance has been diminished to 20 inches, and the system of diagonal strutting has been adopted for the floor as well as the roof. The walls of the level are lined with short lengths of stout planks, which are sawn up by a steam saw-mill at the mine. A complete frame weighs 233 lbs., the average cost is about 38*s.*; and, supposing the average distance apart to be 24 inches, the cost per lineal metre (3·28 feet) will be, with eight years' interest, £4 6*s*., as given above. From this, however, must be deducted the value as old iron, at least 10*s*. per frame, or 16*s*. 8*d*. per metre, which, deducted from the preceding amount, gives £3 9*s*. 4*d*. as the net total cost per metre, or only about two-thirds that of brick walling.

The ironwork is protected by a coating of Ihne's zinc grey, which appears to be perfectly effective as a preservative after nine months' exposure. About 170 metres of level and a shaft 46 metres have been lined with iron, the advantage of its use being especially apparent in the latter case, where more than one-fourth of the labour ordinarily required for timbering shafts has been saved.

H. B.

On Testing Wire Ropes.

By Herr Baumann.

(Zeitschrift für das Berg- Hütten- und Salinenwesens, vol. xxix., p. 57.)

The press with which the experiments recorded in this Paper were made has been erected at the royal colliery of Friederichsthal, near Saarbrücken, and is sufficiently powerful to break steel wire ropes of the largest section used for mining purposes. The press cylinder is supported upon cast-iron standards, giving a clear vertical working space of about 1 metre between the fixed and movable clamps by which the test pieces are held. The latter is upon a cross head parallel to a second one above the ram, the two being connected by side rods. The length of stroke and diameter of the ram are both 300 millimetres, and its effective surface is 707 square centimetres, which at the highest pressure of 200 atmospheres corresponds to a pull of 141·4 tons. The sides of the press cylinder are 100 millimetres, and the bottom 150 millimetres, thick; the side rods connecting the two cross heads are 90 millimetres in diameter. The experiments described were made upon three ropes that had been laid aside after use. The first, a round steel rope of 28 millimetres in diameter with seven strands of seven wires each, with a hempen core of 10 millimetres diameter. The total section of the wires was 250 square millimetres, and the tensile strength when new was guaranteed to be 28·2 tons by the maker, and proved to be 31·8 tons on trial. As it had been exposed to the air for some time, it was considerably and rather unequally rusted. The second rope, also of round steel, was 29 millimetres in diameter, with six strands each of eleven wires 1·65 millimetres, upon a core of seven (one of 1·65 millimetres and six of 1·45 millimetres); the whole have a hempen core of 12 millimetres. The total section, apart from the six thicker core wires, was 200 square millimetres, and the tensile strength 21·89 tons guaranteed, and 26·63 tons actual. This was much better preserved than the preceding one, and the results obtained are considered as more accurate.

The third rope was a flat one of cast-steel wire 60 millimetres broad and 13 millimetres thick, made up of six round ropes each having strands of six 1·45 millimetre wires, and a hempen core of 2 millimetres. The section of metal was 238 square millimetres. When new the tensile strength guaranteed was 25 tons, and the actual breaking strain 30 tons. This had also suffered considerably from rusting.

There being no means of applying the press to the lifting of heavy loads of known weight, the loss due to the friction of the hydraulic packing-leather could not be directly observed. It was therefore calculated according to Reuleaux' formula (given in the "Constructeur," 3rd edition, p. 604).

$$\frac{F}{P}=\frac{1}{D},$$

when F = friction of ram, D = diameter of ram, P = load upon it. Further, if

p = pressure per square centimetre = 1·033 observed gauge pressure in atmospheres;
p_1 = weight of ram and moving parts attached to it;
q = section of ram in square centimetres;
s = effective strain on rope.

$$P=pq\ F=\frac{pq}{D}-\frac{p_1}{D},$$

$$s=pq-p_1\left(\frac{pq}{D}-\frac{p_1}{D}\right)=\frac{D-1}{D}\,pq-\frac{D-1}{D}\,p_1=\frac{D-1}{D}\,pq-C.$$

From which the following expression was obtained:

$$s = 727{\cdot}75\,a - C;$$

which gives the actual strain on the rope s from the observed gauge pressure in atmospheres a. C being a constant whose average value varied with the weight of the moving parts, from 1,375 to 1,435 kilograms.

The chief object of the experiments was to determine the value of different methods in use for attaching ropes to the drawing cages. These were:—

1. Baumann's method, in which the end of the round rope is fixed in a conical box by three wedges, the strain being uniformly distributed by a hard metal packing whose surface is accurately moulded to that of the rope.
2. A similar method to the preceding, but without protecting casing between the rope and the faces of the wedges, which are rough and hardened.
3. The ends of the wire were untwisted so as to nearly fill a conical box, and secured by an annular wedge.
4. Like No. 3, with the end secured by a conical plug.
5. Similar to 3 and 4, the joints made by running in lead, zinc, or hard composition metal.

6. End turned into a loop and secured by pairs of iron rings, driven home by blows upon an anvil. Length of joint, 700 millimetres.

7. Loop with ends secured by three clamps with two bolts to each. Length of joint, 500 millimetres.

8. Loop with three clamps having four bolts to each. Length of joint, 600 millimetres.

Fastening.	Breaking strain.		
	Round Rope of 28 mm.	Round Rope of 24 mm.	Flat Rope 60 × 13 mm.
	Tons.	Tons.	Tons.
Roughened vice jaws . .	28·3—28·8	24·1—24·6	29·7
Clamp No. I. .	27·7	24·1	.. ..
" " II. .	23·3—25·5	22·6—23·4	28·1—30·3
Ringwedge " III. .	15·7—16·4	6·6—12·8	.. ..
Plug " IV. .	16·8—24·8	15·0—22·6	.. ..
Lead joint " V. .	12·1—16·1	12·1—18·3	5·2
Zinc " " " .	19·3—24·1	20·1—23·0	28·5—29·2
Hard metal joint " " .	24·4—25·9	23·0—23·4	17·5
Loop " VI. .	10·2—11·3	16·8—17·9	.. ..
" " VII. .	15·3—27·7	13·8—22·9	24·8—29·5
" " VIII. .	19·7—27·7	15·3—23·7	29·1—30·2

The variations in the above figures are caused by the rope slipping in the holder before the actual breaking strain was reached. This was especially the case with the lead joint No. V., where the soft metal was invariably compressed and the rope was pulled out of the joint. Better results were obtained with zinc and hard metal, but the individual differences show that the metal must be cast at a high temperature to make a proper joint when the wire is likely to be overheated whereby its tenacity is diminished. The best and most uniform results were obtained, as might have been expected, with the first method, where the strength of the joint was nearly equal to that of the whole rope. The method of securing an eye with rings driven on proved thoroughly worthless, as the rings invariably slipped at a comparatively low strain. The latter defect was also observed to some extent when clamps with only two bolts were used, but those with four bolts held the rope much better.

H. B.

The Lignite Mines of Sagor. By J. Jugek.

(Oesterreichische Zeitschrift für Berg- und Hüttenwesen, vol. xxix., p. 5.)

The coalfield of Sagor, situated in north-eastern Carinthia, is of oligocene (or lower miocene) age, and forms a small steeply-folded basin extending for about 2,000 yards in length, and 1,100 yards in breadth. The coal, which is continuously exposed along both lines of outcrop, dips very steeply inwards, the inclination being 55° on the northern and 70° on the southern side; this, together with the great thickness of the seam, from 39 to 49 yards real, or 65 yards when measured horizontally, renders a special system of working necessary. In some places the seam is divided in an upper and a lower one, which, however, only corresponds to a difference in the composition; the former, which is of better quality than the latter, is 12 yards thick, of a dull appearance, and conchoidal fracture; the proportion of ash varies from 2 to 6 per cent., and that of contained water, from 14 to 21 per cent. Where the seam is thickest no distinction of upper and lower coal is made, the whole being taken out together.

The system of working is that by horizontal stages with complete filling of the excavated ground. The stages are 5 metres vertically apart and are taken away in two heights commencing with the lower one. In the case of the upper seam alone being worked, a shaft or inclined plane is sunk in the lower seam, near the line of parting, between it and the upper one to a depth of 60 to 80 metres, when a cross cut is driven nearly over to the roof, from which a main level is carried right and left along the course of the seam to the boundaries, usually transverse faults, which limit the lengths of the districts to between 140 and 300 metres. A smaller shaft sunk parallel to the first in the upper seam serves as a ladder or footway shaft, and a third, placed below it, is provided for bringing in earth or rock for stowing the excavated spaces. From the inclined plane cross-cuts are driven at vertical distances of 5 metres apart, and from these levels are carried along the strike in the manner already described. The lower half of the stage, 8 feet 2 inches, is then laid in as a kind of pillar-and-stall work, the pillars being very long in comparison to their breadth, and the coal is removed, the upper part, or roof coal, being supported by door-frame sets of timber. The coal as broken is taken to the inclined shaft, braked down to the level below, and drawn by horses to the main engine shaft. When the lower coal has been completely taken away, and the filling has had time to consolidate, a new working level immediately above the former one is driven in the upper coal and the process is repeated as before. However, as this second level has stowed waste both above and below it, it is necessary to secure it by complete door-frame timber sets. As the lower stage is exposed by the removal of the upper coal, the timbers that have been left behind in the first working are as much as possible drawn out by a chain-and-lever purchase, which can generally be done if the packing material does not contain much clay, a premium of ten kreutzers being paid to the miners for every serviceable piece of timber recovered. It was at first thought unnecessary to give this, as it was supposed that the saving of labour in preparation of new timber would be sufficient inducement to cause the men to recover the old sets as far as possible; but this was not found to be the case, and they preferred as a rule to abandon them.

Where both the upper and lower seams are worked, the principle is modified by the use of three parallel working levels on each stage instead of one, and where the dip is low (55°) the shaft for passing the loaded wagons down to the driving level is vertical instead of following the inclination of the seam. The waste material is in this case obtained, not from the surface, but from so-called "mills," or chambers which are excavated in the white plastic clay below the seam by extensions of the main cross-cuts of each stage. This material is better than that brought from the surface, as it does not contract so much in packing; but on this account it is of less value in stopping fire, when the coal ignites spontaneously, as it formerly did very frequently. The bituminous shale forming the roof is readily inflammable, and it is therefore necessary to pack up the ends of the levels carefully as the coal is removed, to avoid exposing it to the air as completely as possible.

The yield of the seam is at the rate of about 1·24 ton per cubic metre, of which 55 per cent. is lumps, 5 per cent. slack or dust, and 20 per cent. shale. The latter, resulting from included partings in the seam, is picked out and thrown away, but beyond this there is no loss of coal, the whole of the solid seam being completely removed. The cost of getting, including all preliminary and filling works, is from 4*s*. to 4*s*. 8*d*. per ton, of which 2*d*. to 5*d*. represents the value of the wood expended. The packing material averages from 8*d*. to 10*d*. per cubic metre (1·3 cubic yard). The main draining-shaft and the levels connecting it with the workings are driven in the plastic clay below the coal, which swells up to many times its original volume when brought in contact with water. The smaller levels are secured by complete elliptical walls with an invert water-channel, in a single ring of masonry set in cement, but in the adits the masonry is of a much heavier character. The templets in the ellipse are made of rails curved to the proper shape and joined by a fish-plate at the top. These are easily removable and take up but little space, so that the level can be used while the walling is being built. The main driving-shaft is lined with frames of Bessemer steel of H section 16 inches apart, picked in behind with closely-driven oaken wedges upon a lining of cement concrete. Between the months of November and March, inclusive, no artificial ventilation is required, but during the remainder of the year a Guibal fan is used. The air is distributed through rectangular zinc tubes of 16½ inches × 9½ inches section, which are perfectly efficacious at the greatest length yet in use, about 1,370 yards. These are made in lengths of 6½ feet, and cost about 14*s*. 6*d*. each.

H. B.

On Slags. By A. Ledebur.

(Zeitschrift des Berg- und Hüttenmännischen Vereines für Steiermark und Kärtnen, vol. xiii., p. 53.)

The fact that the presence of magnesia in the limestone used for fluxing in iron smelting, influences the fusibility of the slag formed, is well known, but, as the Author points out, the quantitative limits of the effect have not hitherto been investigated. He has, therefore, experimented with various mixtures of fluxes, so arranged as to give slags of definite molecular constitution. These were fused in charcoal-lined crucibles, with known weights of a cast iron, specially prepared for the purpose, containing some manganese and 2·3 per cent. of sulphur.

The materials used were:—

(1) A pure crystalline limestone, containing 2·1 per cent. of silica.
(2) A dolomitic limestone, containing 11·1 per cent. of silica.
(3) China clay.
(4) Pure calcined magnesia.
(5) Pure silica.

Three series of experiments were made, the first with slags of the form $R^{ii}_2SiO_4$ (singulo, or bibasic silicates); the second of $R^{ii}_3Si_2O_7$. (Four-third or tribasicquadri silicates); and the third of $R^{ii}SiO_3$ (bisilicates or normal silicates). Each series contained six assays, two containing only lime, two with magnesia alone, and two with dolomite; in all cases alumina was present in the constant proportion of one-fourth of the sum of the lime and magnesia. The sulphur contents of the buttons of metal and of the slags were determined in all cases where the metal was actually melted. The results were:—

——	Character of Slags.	Metal.	Sulphur in Slag. Per cent	Sulphur in Metal. Per cent.
	I. Bibasic Silicates.			
1 Lime only . .	White and stony, with shots of metal.	Slightly graphitic.	1·445	0·079
2 Magnesia only .	Blackish grey, with less iron than preceding.	White.	1·069	0·260
3 Lime & Magnesia	Grey porcellanic, with large iron shots.	Mottled on fracture.	1·134	0·154
	II. Tribasic-Quadri Silicates.			
4 Lime only . .	Bluish white porcellanic, with few shots of iron.	Penetrated with plates of graphite.	1·235	0·038
5 Magnesia only .	Could not be melted.			
6 Lime & Magnesia	Greenish white crystalline.	White.	1·265	0·109
	III. Normal Silicates.			
7 Lime only . .	Brownish vesicular.	White shots.	0·681	0·357
8 Magnesia only .	Bright green stony.	White.	0·290	0·391
9 Lime & Magnesia	Olive green glassy.	White.	0·801	0·408

The Author next considers the question of the action of manganese in iron with reference to sulphur in the presence of other metals, and points out that when molten iron is exposed to the air in a foundry ladle the scum thrown up is often notably rich in sulphur and manganese. In one case this scum contained sulphur 0·22 per cent., and manganese 5·19 per cent., the relative proportion of these elements in the metal being 0·05 and 2·62 per cent. respectively. Another question, that of the probable condition of sulphur in iron furnace slags, *i.e.*, whether in combination with calcium or manganese, has also been investigated, but without very decided results. The blue colour of certain charcoal furnace slags appears to be due to sulphide of manganese, as it only appears when some manganese is present, and the lower oxide of that metal does not communicate a blue colour to vitreous fluxes. Two experiments made by passing chlorine, perfectly dried and freed from hydrochloric acid, at a strong red heat over slags from the puddling, and Bessemer processes, appeared to bear out this view, as the whole of the sulphur was volatilized, together with some manganese as chloride; but the Author points out a possible source of error, indicated by the circumstance that the whole of the ferrous oxide in wood slags is by this treatment converted into ferric oxide and ferric chloride, the latter volatilized, and it is quite possible that the lower oxide of manganese may behave similarly. Attempts to obtain metallic manganese and sulphide of calcium by heating sulphide of manganese with carbon, and materials to give a very basic calcareous slag, and the reverse experiment of heating 85 per cent. manganese metal with gypsum and carbon failed; as it was impossible to bring such mixtures into a state of fusion.

H. B.

The Qualities of Iron and Steel.

(Organ für die Fortschritte des Eisenbahnwesens, supplement, 1880.)

The German railway union, which at the present time includes fifty-three German, thirty-seven Austrian, and eleven Dutch and Belgian lines, has collected the results of the investigation into the properties of iron and steel, which was undertaken at the Munich meeting of July 1876, when the following resolutions were agreed to as a basis:—

a. A definite public classification of iron and steel is in the highest degree desirable.

b. In carrying out this classification, official testing stations are required, in properly selected localities, where anyone bringing samples may have them tested at a fixed rate of charge.

c. Some of these should be combined with experimental stations, where experiments on a larger scale can be conducted, under proper direction, upon the qualities to be desired in material for particular purposes.

The arrangement of certain details was entrusted to the technical committee of the union, who, in November 1876, nominated a sub-committee on the classification of iron and steel, to whom the further investigation of the subject was relegated. This sub-committee, which consisted of Messrs. Wöhler, Funk, Brockmann, Hornbostel, Stambke, Mahlor, Bender, Lockner, Nowotny, and von Becker, in December 1877, presented a report to the various Governments interested, containing much valuable information. The sub-committee are of opinion that the disputes and complaints between contractors and consumers of railway plant are due, in great part, to the circumstance that the quality of the articles is not as exactly specified as the quantity. For example, in the case of articles to be delivered by weight or measure, it is certain, as a natural consequence, the delivery would be made upon the smallest exact unit of the kind, and in like manner, when the quality is not accurately specified, the most cheaply produced article, and therefore the lowest quality, would be supplied, and those who did not conform to this practice would be excluded from the competition.

The iron and steel industry is at present in such a position that the State must call upon it to find means to remedy the numerous deficiencies affecting its production. What these necessities are, and to what extent they occur, will be seen from the following figures, taken from the tables containing the results of the numerous experiments made on the tensile strength of materials :—

	Absolute Strength varied between Kilograms per square centimetre (0·00635 ton per square inch);	And the Contraction of the Fractured Area between Kilograms per square centimetre. Per cent. Per cent.
A. Bessemer steel . . .	4,350 and 7,750	4 and 50·5
B. Crucible cast-steel . .	4,760 „ 8,960	4 „ 47·0
C. Boiler-plate, longitudinal	4,020 „ 4,100	8 „ 24·0
D. Bar-iron	3,210 „ 4,030	9 „ 44·0

This irregularity between nominally similar materials, which may be taken as synonymous with want of safety in use, is found not only when the products of different works are compared, but even among samples of the same kind from the same works. While on the other hand, the uniformity of the product from a certain small number of establishments, shows that the attainment of such regularity of quality is quite possible.

Testing stations should be combined with weights and measures gauging offices, or technical educational institutions; the number and position of such stations can only be found by experience. As the introduction of the methods of describing quality by the coefficients of tensile strength and malleability, as used by scientifically trained technologists, into commerce could only be done with difficulty, and might lead to such misunderstandings as would be likely to bring the whole purpose of the scheme into disrepute, it appears best to adopt a simple classification of the metals, based upon the adoption of certain minimum limits of tenacity and toughness. These limits should be so adapted as to be capable of revision from time to time, as improvements in the manufacture may require.

For present purposes, the following appear to be proper values:—

A. BESSEMER-STEEL, CAST-STEEL, MARTIN-STEEL, AS CONSTRUCTIVE MATERIAL, *e.g.* FOR RAILS, AXLES, TIRES, &c.

First quality with three sub-heads.

	a. Hard.	*b.* Medium.	*c.* Soft.
Minimum breaking strain in kilograms per square centimetre = 0·00635 ton per square inch	6,500	5,500	4,500
Minimum contraction of area at fracture	25 per cent.	35 per cent.	45 per cent.

In order to satisfy this quality, the above figures must be attained or exceeded. The appearance of the fracture must be uniform and free from either longitudinal or transverse cracks.

Second quality with two sub-heads.

	a. Harder.	*b.* Softer.
Minimum breaking load . .	5,500	4,500
„ contraction . . .	20 per cent.	30 per cent.

B. MALLEABLE IRON.

	First quality.	Second quality.
Minimum breaking strain .	3,800	3,500
„ contraction . . .	40 per cent.	25 per cent.

C. IRON PLATES.

		First quality.		Second quality.	
			Per cent.		Per cent.
Minimum breaking strain	*a.* With the grain,	3,600	25	3,300	15
„ contraction .	*b.* Across „	3,200	15	3,000	9

Materials of lower tenacity or ductility than defined by the above limits should not be admitted to classification, but the exclusion of unclassified material from trade would not be desirable. It would be sufficient to make the possibility of anyone obtaining any desired quality a certainty.

Entirely distinct from the determination of the properties of a given material, is the question of what these qualities should be for material destined to any particular use, as, for example, in the construction of boilers, &c. This is a matter for which the establishment of experimental stations would be desirable, and of these two would be sufficient for the requirements of the German-

Austrian railway union. They should be established at different places, and each would control and supplement the work of the other, their main object being to tell the producer what he should produce, but not how he should produce it.

The propositions put forward in the report are based upon the results of experiments made in the mechanical technical laboratory of the Munich Polytechnic High School, under the direction of Professor Bauschinger, between November 1876 and May 1877. At the general meeting at the Hague in July 1877, it was resolved to carry on these experiments, combining them with the data obtained from actual use, in order to obtain data as to the conditions to be inserted in specifications for new material. In furtherance of this object, the experiments were continued until June 1878, embracing in all—

	130	samples.	Cast (crucible and Bessemer) steel	for axles.
	170	„	„ „	„ tires.
	142	„	„ „	„ rails.
	336	„	Bar-iron.	
	151	„	Boiler-plate, longitudinal.	
	142	„	„ transverse.	
Total	1,071	„		

The test pieces were uniformly 400 millimetres (15·75 inches) long, and 25 millimetres (0·945 inch) broad. The experiments were made with one of Werder's testing machines, the constants of elasticity being obtained with Bauschinger's reflecting apparatus. The results are exhibited in a series of tables, and illustrated graphically on four plates. In addition to the above, experimental results were communicated to the commission from eight independent parties.

Experiment shows that, when the breaking strain in kilograms per square centimetre is taken as the measure of tensile strength, and the percentage contraction of area as that of malleability, that the sum of those qualities fairly expresses the quality of the material. The question as to quality of material best for any special purpose is yet to be solved. This may be done either by experiment or from the results of experience on a large scale. The first of these methods is intended to be carried out in the experimental stations, whose establishment by the different Governments is recommended as desirable by the commission; and although this recommendation has as yet produced no decided result, the propriety of founding the stations has been generally recognised. The second method, that of experience on the large scale, is within the province of the commission, and carefully compiled statistics of the conditions of rails and tires, combined with careful testing, would doubtless in no very long period give results of great value. Although, therefore, the commission does not consider its experimental researches as complete, it is thought that the general conditions of quality necessary for specification of axles, tires and rails, may be laid down on the terms adopted at a general meeting held at Salzburg in May 1879, viz.—

Cast-steel Axles.

Minimum strength	. .	50 kilograms per square millimetre.
Maximum contraction	.	30 per cent.

Sum of both to be not less than 90.

These are to be so understood that a strength of 50 kilograms, with a contraction of 40 per cent., or of 60 kilograms and 30 per cent., or intermediate numbers in proportion, may be considered as equivalent.

Cast-steel Tires.

For locomotive wheels not subjected to action of brakes.

Minimum strength	. .	60 kilograms per square millimetre.
Minimum contraction	.	25 per cent.

For tender- and carriage-wheels.

Minimum strength	. .	45 kilograms per square millimetre.
„ contraction	.	35 per cent.

Steel Rails.

Minimum strength	. .	53 kilograms per square millimetre.
„ contraction	.	20 per cent.

Minimum sum of both, 85.

The limits of variation in all factors to be allowable in regard to axles and tires depend upon local conditions as heretofore.

For rails, the permissible limits might be so varied that a minimum strength of 65 kilograms, with a minimum contraction of area of 20, would be accepted as synonymous with 50 kilograms and 35 per cent., and the same for intermediate qualities.

The tests to be made upon pieces shaped to a uniform size and section. While breaking tests are essentially prescribed, the railway authorities reserve the right of making impact, flexure, and transverse loading tests as before.

Malleable-iron Boiler-plates.

a. In the direction of rolling.

Minimum strength	. . . .	3,400 kilograms per sq. centimetre.
„ extension after fracture		12 per cent. of the original length as measured on a length of 200 millimetres (7·874 inches), including the fracture.

b. At right angles to the direction of rolling.

Minimum strength	. .	3,000 kilograms per square centimetre.
„ extension	. .	8 per cent.

In conclusion, it may be stated that the Prussian Ministry of Public Works have, since July 1880, adopted the above quantities as standards for specification of materials for the State Railway Department, as have also the larger number of the German and Austrian railways forming part of the union. Those among the steel manufacturers, who at first were strongly opposed to these conditions have also generally signified their acquiescence.

H. B.

On the Relative Power required to Roll Iron and Steel.

By F. Braune.

(Zeitschrift des Vereines deutscher Ingenieure, vol. xxv., p. 298.)

In this Paper some details are given of experiments made to determine the increase of motive power necessary to adapt a mill for rolling steel instead of iron.

The mill was a three-high mill used for rolling deep joists 60 feet long, and it was required to roll the same section and length in steel. The results of the experiments show that when the circumferences of the rolls are speeded for steel in the proportion of 14 to 11 faster than for iron, the power required for steel is about three times more than for iron. The Author considers that rolling-mill engines are often made unnecessarily large; he recommends the proportions adopted by Van den Kerkhove of Ghent, whose engines are single-cylinder non-condensing, with Corliss valve gear: the cylinder diameter is 914 mm. (36 inches), stroke 1,524 mm. (5 feet), revolutions per minute seventy-five, and weight of fly-wheel 50 tons. These engines indicate about 800 HP., with 60 lbs. steam cut-off at half stroke.

W. P.

The Amount of Manganese required to Remove the Oxygen from Iron, after it has been blown in a Bessemer Converter.

By S. A. Ford.

(Read at the Philadelphia Meeting of the American Institute of Mining Engineers, February 1881.)

The Author calls the attention of Bessemer steel manufacturers to some facts in regard to the action of the manganese in the spiegel, with the oxide of iron in the blown iron. Gautier asserts that the oxygen is united with the iron as a magnetic oxide, which is reduced to a protoxide by one atom of the oxygen uniting with one atom of manganese; the oxide of manganese and the protoxide of iron thus formed unite with the silica produced by the oxidation of the silicon in the pig iron. Many manufacturers assumed, as a basis of calculation for the addition of spiegel, that the blown iron contains 0·29 to 0·35 per cent. of oxygen, and that the whole unites with the manganese; whilst in fact, according to Gautier, one-fourth only is removed, though the Author finds that this proportion is not quite constant. At the Edgar Thompson works there was recently some difficulty due to an excess of manganese in special steels, in the manufacture of which 200 lbs. of 69 per cent. ferro-manganese had been added to 17,900 lbs. of iron. On the 0·35 per cent. basis there would have been 56·38 lbs. of oxygen in the blown iron, which would require 193·88 lbs. of manganese for its complete removal as oxide of manganese; but there was only 138 lbs. of manganese in the ferro-manganese, therefore none should have been found in the steel, while in truth 0·716 per cent. were shown by analysis.

To investigate this discrepancy the Author made a special examination: he found in the pig iron used for the blow 1·945 per cent. of manganese, in the same iron molten as it went into the converter from the cupola 0·987 per cent., and in the same iron when blown 0·024 per cent. 17,900 lbs. of this blown iron had added to it 185 lbs. of 68·9 per cent. ferro-manganese, while the resulting steel contained 0·608 per cent. manganese. In blowing, 0·63 per cent. of the iron was oxydised, which would make 0·87 per cent. of magnetic oxide, giving 0·24 per cent. of oxygen, of which, on Gautier's assumption, only ¼th 0·06 per cent. would be removed, and requiring for this purpose only 48·23 lbs. of the 68·9 per cent. ferro-manganese, instead of the 185 lbs. used. On this theory the Author calculates that the steel ought to have contained 0·609 per cent. manganese, which approximates sufficiently closely to the 0·608 per cent. actually found; and he now believes that the amount of manganese that will be contained in steel may be calculated beforehand to within 0·02 or 0·03 per cent. of the actual quantity.

C. S.

A New Bottom for Bessemer Converters. By C. F. MANNESS.

(Read at the Philadelphia Meeting of the American Institute of Mining Engineers, February 1881.)

The Author describes a suggested improvement in converter bottoms that does not appear as yet to have been in practical operation, and a further Paper is promised. He states that, with all the improvements and alterations made in late years in Bessemer plant, the converter bottom has remained almost unchanged, except as to modifications in the size, nature, and position of the joint connecting it to the main body of the converter. The manner in which the bottoms wear indicates that the metal, when subjected to blast, is thrown into small but powerful eddies encircling each air-jet; the tuyeres, which have always been vertical, are thus worn away, whilst the solid part of the bottom is yet comparatively good. The Author suggests that the bottom be left solid, whilst the tuyeres should be placed in an inclined position, at an angle of about 45°, entering the vessel in the side wall next to the solid surface of the bottom; the air would thus be injected in an oblique direction, which should keep it longer in the metal, so that a given volume of air would do greater service by being more thoroughly consumed, and thus shorten the blow. Also the tuyeres should last longer, as the falling metal would not have so prejudicial an effect on the angular as on the vertical tuyeres; and as the solid part of an ordinary bottom lasts so much longer than the tuyere part, a bottom entirely solid should stand a great number of blows.

C. S.

The Strongest of the Bronzes. By R. H. Thurston.

(Trans. Amer. Soc. C.E., January 1881.)

Mr. Thurston devised a method of planning his investigations of the properties of copper-tin-zinc alloys, involving the plotting of a series of contour lines, expressive of, say the tensile strength, or of other properties of such alloys, compounded in varying proportions. It is based on the property of equilateral triangles, that if from any point in the triangle, perpendiculars be drawn to the sides, the sum of the perpendiculars is equal to the altitude of the triangle. Consequently, taking the length of a side as 100, representing the alloy, the lengths of the three perpendicular may represent the several percentages of the constituents, and it is evident that every possible combination of the three constituents may be represented by some one point in the triangle. If, then, a considerable number of alloys be plotted within the area of the triangle, according to their composition, and a wire be erected at each corresponding point at right angles to the plane of the triangle, proportional in length to the tensile strength of the alloy, an undulating area is generated, or punctuated, corresponding to the varying heights of the wires. The spaces between the verticals are filled up with clay or with plaster, and carefully moulded until the tops of all the wires are just visible, shining points in the now smooth surface of the model. The surface thus formed has a topography characteristic of the alloys examined, and its undulations present the characteristic variations of quality, with changing proportions of the three constituents.

It may easily be comprehended that an undulatory surface thus wrought out would culminate at a point, or a limited area of maximum elevation, indicating the component proportions of the alloys of maximum strength. Thus it was that Mr. Thurston arrived at the deduction that the alloys of maximum strength were grouped about a point, not far from that which represented the proportions of 55 of copper, 43 of zinc, and 2 of tin, and a tensile strength of 65,000 lbs. per square inch.

The alloy which combined toughness with strength in the highest degree, contained a less proportion of tin than the foregoing. The composition is not here quoted, for there is an error in the proportions as stated in the Paper.

D. K. C.

Method for the Estimation of Manganese in Spiegels, Irons and Steels. By S. A. Ford.

(Read at the Philadelphia Meeting of the American Institute of Mining Engineers, February 1881.)

A short and accurate method for the estimation of manganese in iron and steel is of great importance to Bessemer works, and the Author describes in detail the process adopted by himself, by which three or four determinations may be made in two hours. By his method, which is equally available for blast furnace slags, there is no large precipitate to wash as in the Pattinson process; the necessity for several standardised solutions is avoided, and the results accord very closely with those obtained by the tedious acetic process.

The process is based on the reaction first described by Beilstein and Jawein. The steel, spiegel or iron, is dissolved in strong nitric acid; after evaporation it is again dissolved in hydrochloric acid, evaporated, re-dissolved in strong nitric acid, and whilst boiling chlorate of potash is added. After the whole of the manganese has been oxydised, the solution, to which more chlorate of potash has been added, is filtered through asbestos. All the manganese will remain upon the filter; the Author has never found a trace in the filtrate. The filter, with its contents, is placed in a beaker, hydrochloric acid is added, and the whole boiled until the binoxide of manganese is dissolved as chloride. After the asbestos has been filtered off, wash with hot water, nearly neutralise with ammonia, and add acetate of soda; after further boiling and filtering add an excess of microcosmic salt; make slightly ammoniacal, and boil, stirring till the precipitate assumes the silky appearance of phosphate of ammonia and manganese; allow to settle; filter, wash, dry, ignite, and weigh as pyrophosphate of manganese.

C. S.

The Conservation of Electricity. By G. Lippmann.

(Comptes rendus de l'Académie des Sciences, vol. xcii., pp. 1049–51, pp. 1149–52.)

Quantity of matter and quantity of energy are not the only dimensions that remain invariable; quantity of electricity has the same property. If a known phenomenon be considered as a whole, the distribution of the electricity may be observed to change, but the sum of the quantities of free electricity will never vary. If the electric charge shows positive variation at certain points, it will show at other points negative variation, and the algebraic sum of all simultaneous variations of charge is always nil. This law the Author terms the principle of the conservation of electricity, and it can be extended to all known phenomena.

To translate into analytic language, let x and y be two independent variables, upon which depend the quantity of electricity that a body receives; x may be, for example, the potential that this body acquires, and y its capacity or even a length, pressure, or temperature, &c., of which this capacity may be a function. Let dm be the quantity of electricity received by the body, when x increases by dx, and y by dy; then

$$dm = \mathrm{P}\,dx + \mathrm{Q}\,dy,$$

P and Q being two functions of x and of y. The Author asserts that the principle of the conservation of electricity is expressed by the condition that dm may be an exact differential. Let an electric phenomenon be produced in two portions, A and B. Let a and b be the variations of charge simultaneously upon these two portions; then, by this principle, $a + b = o$. In the case where A completes a cycle, or in that where its final state is identical with its initial state, $a = o$, and consequently $b = o$. This may be written $\int dm = o$. So that an integral $\int dm$ may be nil for a complete cycle, it is necessary and sufficient that dm should be an exact differential, which is in accordance with the known condition of integration:

$$\frac{\delta \mathrm{P}}{\delta y} = \frac{\delta \mathrm{Q}}{\delta x}.$$

This is the general analytic expression of the principle of the conservation of electricity. The principle of the conservation of energy is equally expressed by a condition of integrability. Thus are obtained two distinct equations, of which the simultaneous application to several known phenomena prognosticates the existence and dimensions of new phenomena.

In the subsequent paper noted the Author makes application, in a recondite manner, to Boltzman's discovery, in 1875, of the dielectric power of gases.

P. H.

Note on a New Form of Galvanometer for Powerful Currents.

By Prof. C. F. Brackett.

(American Journal of Science, 1881, vol. xxi., p. 395.)

Two stout copper or brass hoops, of different diameters, are turned in a lathe. They are then each cut open at one point, and joined to each other concentrically by soldering a piece of metal having the same cross-section as that of the hoops, and of suitable length between the ends on one side of the cut. The hoops are kept concentric by means of pieces of hard rubber. The three ends of the system thus arranged and set upright on a proper base board, are joined to binding screws. The differential action on a needle placed at the centre, or on the axis of the hoops passing through their centre, depends on the different distances of the two equal and opposite currents. The instrument may also be used as a tangent galvanometer.

If A and B are the free ends, and C the point of juncture, by joining through A and B differential action is obtained; by joining through C and A or B, the action is that of a simple tangent galvanometer.

E. F. B.

The Efficiency of Secondary Batteries. By E. Reynier.

(Comptes rendus de l'Académie des Sciences, vol. xcii., pp. 1093–6.)

Work by secondary batteries includes two phases—the charging of the accumulator by the action of an external electric source, and its discharge in the circuit worked. Each of these operations includes a loss. In seeking the expression for efficiency, let E_0 be the initial electromotive force of the source, R_0 its resistance, E the electromotive force of the secondary battery, R its resistance, E_1 the difference of potential at the two extremities of the conductor worked, R_1 the resistance of this conductor, t the time of charge, t_1 the time of discharge. The work T_0 expended in charging will be (supposing it to be constant) $T_0 = E_0 \frac{E_0 - E}{R_0 + R} t$. The work T utilised in the resistance worked will be $T = \frac{E_1^2}{R + R_1} t_1$. To find the ratio of these works, it is necessary to express t_1 in function of t. It may be arrived at by considering that the quantity of electricity Q is the same in the circuits of charge and discharge (which needs experimental verification), and that this quantity is proportional to the products of the quantities of the currents by the times, whence the equation

$$\frac{E_0 - E}{R_0 + R} t = \phi = \frac{E_1}{R + R_1} t_1 \text{; and whence } t_1 = \frac{t \frac{E_0 - E}{R_0 + R}}{\frac{E_1}{R + R_1}}.$$

By substitution, the efficiency $\phi = \frac{T}{T_0} = \frac{E_1}{E_0}$.

The efficiency is thus expressed by the ratio between the difference of potential at the two ends of the resistance worked and the initial electromotive force of the source of electricity; it is independent of resistances and of the values of the times of charge and discharge. This is based on the supposition that the work produced was the heating of a resistance; if the discharging current actuated a circuit which was the seat of an electromotive force, in an electric motor for example, the expression for efficiency would not be altered. But E_1 should then express the contrary electromotive force of the motor at the origin of the induction.

In practice, the resistances of the circuits should be taken into consideration. On account of the low internal resistance of M. Faure's secondary battery, 80 per cent. efficiency can be attained with advantageous conditions of charge and discharge. The constants of the Faure battery are, for the small size of the 7·5 kilogrammes battery, $E = 2 \cdot 15$ volts, $R = 0 \cdot 006$ ohm, making $E_0 = E \times 1 \cdot 1 = 2 \cdot 36$ volts, $E_1 = E\,0 \cdot 9 = 1 \cdot 93$ volts, $R_0 = R = 0 \cdot 006$ ohm, $R_1 = R \times 9 = 0 \cdot 054$ ohm. The work expended during charging will be $\frac{E_0^2 - E\,E_0}{g\,(R_0 + R)} = 4 \cdot 24$ kilogrammetres per second and per couple, which admits of saturating the battery in a charging time much shorter than is usual. The work returned per second and per couple during the discharge will be equal to $\frac{E_1^2}{g\,(R + R_1)} = 6 \cdot 3$ kilogrammetres. As to efficiency, it is, under these conditions, $\frac{E_1}{E_0} = \frac{0 \cdot 9}{1 \cdot 1}$, or 81 per cent.

P. H.

On the Contrary Electromotive Force of the Electric Arc.

By J. Jamin.

(Comptes rendus de l'Académie des Sciences, vol. xcii., pp. 1021–3.)

Edlund was the first, the Author claims, to indicate the existence of a contrary electromotive force in the electric arc, and Le Roux has demonstrated the fact. It has analogy to the polarisation of electrodes; it is developed as soon as the arc is established, increases rapidly to a fixed limit, and then opposes, as with polarised electrodes, a resistance to the passage of the current equivalent to ten or fifteen Bunsen elements. If a battery be the source, it is necessary to overcome this resistance by an equal number of elements, to which must be added about twenty-five others to obtain a sufficient arc. It is known that thirty or forty Bunsen elements are necessary to illuminate an ordinary regulator; but the work is that represented only by twenty-five elements. For this reason it is difficult to illuminate two or a greater number of arcs in the same continuous current, as each arc presents an inverse or contrary electromotive force. The Author claims the conditions to be different with alternating currents. After the current has passed in one direction and polarisation has been established, the normal current is interrupted only to be reproduced in an opposite direction, and during this latter epoch the two electromotive forces, instead of counteracting, are superposed. If the inversions are consecutive at only long intervals, the resistance to the passage of the current will have time to attain its maximum, as with the battery; but with the machines the currents are renewed at least five hundred times (*cinq cents fois*) per second. There are then at least five hundred emissions of current with an electromotive force equal to that of the machine, increased by the inverse force created during the preceding emission. It thus becomes feasible to maintain several arcs in the same circuit. It is probable that the period necessary for the inverse force to attain its limit of value is very short, because the number of lamps that may be maintained in the same circuit increases rapidly with the velocity. These contrary electromotive forces may be explained as a Peltier phenomenon. The current that passes from the positive point in the arc heats this point considerably; on the negative point the heating is less, and when the current ceases the difference of temperature of the joint develops a contrary current. As the difference does not occur with alternating currents, the force does not exist.[1]

P. H.

The Graphic Representation of the Properties of Dynamo-Electric Machines. By M. DEPREZ.

(Comptes rendus de l'Académie des Sciences, vol. xcii., pp. 1152–55.)

The theory of magneto-electric machines is well known; but this cannot be said of dynamo-electric machines, in which the current generated by the machine re-acts on the intensity of the magnetic field. The Author proposes a simple graphic method of studying the latter question, which admits of immediately calculating the value of the current generated by a dynamo-electric machine under all conditions of velocity of the ring and resistance of the exterior circuit. This method is founded on the construction of an experimental curve, termed the characteristic of the machine. To construct it, all connection between the ring and the exciting electro-magnets is suppressed, the latter being excited by a foreign source; whilst there is imparted to the ring an arbitrary velocity of rotation, but which must be maintained throughout the experiments. Then the difference of potential is measured between the terminals of the induced circuit. If the quantity of the electro-magnet circuit current be varied, corresponding variations will occur in the induced circuit; and, by taking the quantities of this auxiliary current as abscissæ, and the differences of potential at the terminals of the induced circuit as ordinates, there results the characteristic curve. The difference of potential between the terminals of the induced circuit is, in the Gramme and similar machines, proportional to the velocity of rotation. If the connection between the ring and the exciting electro-magnets be now established, and the machine circuit closed by a wire of known resistance, the curve permits of determining the quantity of the current generated, if the total resistance of the circuit be known. If I be the quantity of the current, E the difference of potential between the interrupted ends of the induced circuit, when the angular velocity of rotation is equal to unity, R the total resistance of the circuit, including the ring, the electro-magnets, and exterior resistance; w the angular velocity of the ring; then $I = \frac{w\,E}{R}$, whence $\frac{I}{E} = \frac{w}{R}$. Now $\frac{I}{E}$ is the coefficient of inclination of a right line passing through the origin and through the point of which the co-ordinates are I and E, and as this coefficient should be equal to $\frac{w}{R}$, the following construction may be concluded: the characteristic having been determined as indicated, it is sufficient to learn the quantity of the current generated under the known circumstances, to draw through the origin a right line, of which the coefficient of inclination is proportional to $\frac{w}{R}$; the intersection of this right line with the characteristic curve will have for abscissa the quantity of the current required, and for ordinate the generative electromotive force of this current. If the energy corresponding to this current be required, it has for expression E I, and to determine it immediately we may construct a second curve, having I as abscissæ and E as ordinates. This method, by simple variation, is applicable to all forms and modifications of dynamo-electric machines.

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[1] Considerable care has been taken with this Abstract to employ as much as possible the words of the Author, on account of the apparent anomalies in the statement, which is essentially hypothetical.—P. H.

P. H.

A Simple Transmission-Dynamometer. By E. Thomson.

(Journal of the Franklin Institute, February 1881, p. 117.)

This dynamometer for measuring the stress in driving belts is a modification of the one invented by Herr von Hefner-Alteneck. Between the driving and driven pulleys an immediate carrying pulley, equal in diameter to the driving pulley, is placed at a distance from it equal to its own diameter. The belt is passed over and under the intermediate pulley, and the upper and lower limbs of the belt are approached to each other between the two pulleys until they each form entering angles of 120°. They are deflected in this manner by means of two small guide or friction-pulleys, hung in a frame which is balanced by a suitably-graduated steelyard on which there is a sliding weight, to balance the difference of stress in the limbs of the belt. The precise angle, 120°, is adopted, because the resultant of the stresses in the two sides or parts of the belt forming the angle is equal to the stress in the belt. This equality holds for each limb of the belt, and the difference of the resultants is equal to the driving stress, as measured on the steelyard.

D. K. C.

Electric Fire-Alarms.

(La Lumière Électrique, vol. iii., pp. 214–217.)

This is one of a series of articles descriptive of fire-alarms, for the protection of storehouses and other buildings, and although it may appear invidious to select only a single system, that of which the description is herewith abstracted only affords evidence of sufficient value. The chief improvement in this arrangement, which includes the usual accompaniments of bell, battery, and resistance bobbins, is in the automatic contact. This is a metallic box enclosing a spiral of two unequally dilatable metals, brass and platinum, for example, in metallic communication with the box. Opposite the free end of the spiral is a contact screw, adjusted to form contact with the end of the spiral at a given temperature. These contact boxes are placed in derivation from a main circuit, which includes a resistance coil before each contact derivation. At the point of observation is a small, differentially wound galvanometer with a rheostat of coils similar to those placed on line. When a contact is established, notified by the ringing of the gong, the galvanometer needle is deflected, and remains so until a corresponding number of coils are introduced on the other circuit from the rheostat; and from this is determined the position of the contact and therefore of the fire.

P. H.

Testing Underground Telegraph Cables. By Dr. Brix.

(Electrotechnische Zeitschrift, January 1881, pp. 3–6.)

In a Paper read before the Electrotechnical Society of Berlin, Dr. Brix describes in detail the methods adopted in practice of testing the underground cables on the lines of telegraph under his direction. The tests are made once a week. In measuring what the Author calls the "copper resistance," that is, the electrical resistance of the copper conductors, great advantages are found in having several wires in one cable. In such a case, the wires may be measured in continuous circuit, instead of making use of an earth return. The importance of this in obtaining exact measurements will be understood when note is taken of the disturbing influences of polarization of earth plates, and the working of other lines having earth plates at no great distance.

At the distant station, the several conductors of the cable are connected together; at the place of measurement, the testing-room of the home station, two of these conductors are connected to the Wheatstone bridge, and the resistance of this wire circuit is measured in the usual way. The battery is not in this case put to earth, but is in communication with the bridge, an arrangement which gives true results, even if one of the conductors has a fault of insulation, for no loss of current can then take place through the fault. When there is a fault of insulation in each of two conductors the case is obviously different, for if these faulty wires were connected up to form a circuit, a leak would occur from one wire to the other through the earth, and a false indication would be obtained. In such a case, the wires must be connected up singly, care being had that a faulty wire be joined to a sound one. When dealing with three wires, the resistance of these singly may be easily found by the method of connecting-up in circuit here referred to. Connection is first made between Nos. 1 and 2, then between Nos. 1 and 3, and lastly between Nos. 2 and 3. The last measurement, deducted from the sum of the two others, gives twice the value of No. 1, and this value deducted from the first two measurements, gives the value of Nos. 2 and 3. In a cable containing seven conductors, seven circuits, made up in like manner, will be sufficient. But in practice nine are formed; the additional labour occasioned thereby is small, and more than compensated by the advantages gained. These nine combinations are so chosen that out of any three of them three circuits may be determined, and that a circuit, say No. 7, may be common to each of the three groups. From these nine measurements are thus obtained three values of No. 7. Each of these values is deduced from three independent measurements, and if these three values agree one with another, there is strong presumptive evidence of their being all correct. A further proof may be obtained by comparing the measurements one with another, when these have been taken always in the same order. The difference between two consecutive measurements must always be about the same in amount. From the copper resistance obtained in this way, after making a suitable reduction for the temperature of the room and the rheostats, the mean temperature of the underground cable is deduced. The measured resistance of the conductors is compared with a standard resistance at a normal temperature of 15° Centigrade.

G. G. A.

Influence of the Aurora Borealis of August 1880, *on Telegraph Lines.* By OBER-POSTRATH LUDEWIG.

(Electrotechnische Zeitschrift, January 1881, pp. 10–15.)

The remarkable display of the aurora borealis which took place on August 12, 1880, exerted a powerful influence on the telegraph lines throughout Germany, and the Author was led by the general occurrence of the phenomenon to institute inquiries throughout Europe, and in some other parts of the world, with the view of ascertaining whether the same effects had been produced in other localities, and on longer and differently constituted lines. The results of these inquiries he has brought together in the present communication, and he has illustrated his observations by a map exhibiting the course of the magnetic storm. It appears from the facts stated in this Paper that all lines of telegraph situate in the northern half of the eastern hemisphere were more or less affected, and that the same influences extended beyond the equator as far as Mozambique and Natal. In America also powerful disturbing magnetic actions were observed from the same cause, though the ocean cables were, as far as the Author could learn, unaffected. The disturbance took the form of currents both in overhead and in underground lines, of varying intensity and duration, and what was most remarkable, as showing variations of intensity in the inducing force, of alternating direction. In some localities, the lines of telegraph running east and west, in others those running north and south, were the most affected. The long lines were found to have suffered more from the disturbance than those in which the earth-plates were nearer together. On some lines communication was for a time wholly interrupted. The effects of this magnetic storm were similar in all respects to those of the storms of 1871 and 1859. As in the latter year, the magnetic disturbance was distributed over the earth in large circles. This is shown in the map which accompanies the Paper.

G. G. A.

The Lichterfeld Electric-Railway.[1] By DR. WERNER SIEMENS.

(Glaser's Annalen für Gewerbe und Bauwesen, No. 96, p. 495.)

The Author, after detailing the difficulties encountered in obtaining a site for the experimental railway which Messrs. Siemens and Halske proposed to construct, more in the interests of science than as a speculation, went on to say that at length the owners of the light railway, lately used for the transport of building material for the military college at Great Lichterfeld, consented to hand over the works, &c., for the use of the company. Messrs. Siemens and Halske, after complying with the requirements of government, at once proceeded to modify the existing permanent way, so as to render it suitable to their purpose, without making any elaborate attempts at securing perfect insulation. Both rails were used as conductors; this necessitated the insulation of the framework of the carriage and the wheels. This line of course is not to be taken as a type or model for an electric railway. The researches on the subject of electro-dynamic force before 1876 were of a scientific rather than of a practical character, but since then the useful application of this power has been steadily developed, first in the production of the electric light, and now as an electro-motor.

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[1] *Vide* Minutes of Proceedings Inst. C. E., vol. lx., p. 503.

The electro-magnectic machines used at Lichterfeld, though differing both in size and construction, were each capable of producing currents of considerable volume and intensity.

Moreover, when the electric carriage was driven, either by horse or steam-power, at a sufficient speed, it produced a current sufficiently powerful, not only to set the stationary engines in motion, but also to perform work. This peculiarity is interesting in more ways than one, for thus it is seen that the carriage which is driven by the action of the primary current, is at the same time itself capable of developing a secondary current in opposition to the primary one, whose useful effect is therefore reduced. This circumstance might be looked upon as the chief impediment to the application of this description of motive power.

The extent to which this secondary current is set up by the electro-magnet on the carriage, as well as its strength, depends entirely upon the speed at which the carriage travels, so that if the force of the primary current is such as greatly to accelerate the motion of the carriage this counter current is developed and reacts on the primary current, so as to reduce its effect and *vice versâ*, the speed is thus always regulated automatically.

The experience obtained on the Lichterfeld railway fully confirms this. For, on a level road, the carriage left to itself travels at a greater speed in proportion to the decrease of the tractive current, until the difference between the primary and the secondary currents becomes a constant quantity, when the speed of the carriage also becomes uniform.

On a rising grade again its speed slackens in proportion to the increase in the strength of the primary current, until the secondary current has become inappreciable, when, as before, a uniform rate is maintained.

Finally, on a falling grade, if it be such as to cause the carriage to travel at a speed considerably greater than that due to the effect of the primary current, the secondary current becomes intensified, and begins to act as a brake, since the carriage comes into play as a machine producing an electro-dynamic current, which is opposed to that developed by the stationary engine. From this reaction the intimate relation between all the parts of the connections in the system is apparent, as is also the necessity for them all being duly proportioned one to another.

In fact there exist certain relations between the fine wire of the machine and the conductors on the line, which make it necessary that the resistance offered by the latter to the passage of the current should be greater than that in the electro-dynamic machine itself.

Given the resistance of the coils of the machine, the line conductors must be designed so as to offer a proportionate amount of resistance, and *vice versâ.*

The loss of power is therefore quite independent of the distance from its source, provided the conductivity of the line is sufficiently increased, and the total resistance does not exceed the theoretically defined limit. This may be accomplished in various ways, viz., by subsidiary conductors, increasing resistance of coils, &c.

Whether it is practicable to work several carriages simultaneously on the same line is a question that can be answered unhesitatingly in the affirmative. It is simply a matter of duly proportioning the external to the internal resistance of the engine.

The connections at the joints of the rails were secured electrically by means of elastic strips of metal soldered at the foot of each rail. The noteworthy features of the electric carriage are (1) an electrical arrangement for reversing, (2) one for controlling the speed, and (3) another for preventing any sudden interruption of the current which is injurious to the engine. The carriage on this line regularly met each train that arrived at the Anhalt railway station. It travelled at the rate of 20 kilometres per hour, as laid down by government, though capable of travelling, with a full load (total weight, 4,800 kilogrammes) at the rate of from 35 to 40 kilometres per hour.

This railway, 2·45 kilometres in length, was opened for traffic on the 16th May, and has since performed its work regularly. Messrs. Siemens and Halske are at present preparing to introduce a similar system on the existing horse-tramway between Charlottenburg and the Spandau Bock, with the difference, however, that the cars are to be drawn by a small engine travelling overhead on an elevated cable line.

W. A. B.

Upon the Production of Sound by Radiant Energy.

By Alexander Graham Bell.

(American Journal of Science, June 1881, p. 463.)

In a previous Paper,[1] the Author having described the experiments which resulted in the construction of the photophone, he now describes the progress made in the investigation of photophonic phenomena since.

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[1] *Vide* Minutes of Proceedings Inst. C.E., vol. lxiii., p. 431.

Whilst in Paris, a means of testing the general proposition that sonorousness, under the influence of intermittent light, is a property common to all matter, occurred to the Author, and the results were communicated to the French Academy on the 11th October 1880, in a note read for the Author by M. Antoine Breguet. As these experiments appear to the Author to have formed the starting-point of the independent researches of M. Mercadier, Professor Tyndall, W. E. Röntgen, and W. H. Preece, he gives a portion of his letter on the subject to Mr. Tainter, his co-experimentalist, from which may be quoted, "Place the substance to be experimented with in a glass test-tube; connect a rubber tube with the mouth of the test-tube, placing the other end of the pipe to the ear; then focus the intermittent beam upon the substance in the tube. I have tried a large number of substances in this way with great success. . . . I would suggest that you might repeat these experiments and extend the results," &c.

Mr. Tainter, in order to study the effects under better circumstances, enclosed his materials in a conical cavity in a piece of brass closed by a flat piece of glass. He gradually discovered that cotton-wool, worsted, silk, and fibrous materials, produced louder sounds than rigid bodies like crystals, or the diaphragms formerly used: he further found that materials of dark colours produced the loudest sounds; and, finally, a teaspoonful of lamp-black, the loudest sound hitherto obtained; and when, on his return to America, Professor Bell smoked the interior of the conical cavity, and exposed it to the intermittent beam, the sound was quite painful to the ear, but even this was made sensibly louder when some smoked wire-gauze was placed in the receiver. When the beam was thrown into a resonator, the interior of which had been smoked over a lamp, the sound was so loud, when the frequency of the interruption corresponded to the frequency of the fundamental of the resonator, that it might be heard by an audience of several hundred people. So loud are the sounds produced from lamp-black, that this substance may be used in an articulating photophone in place of the electrical receiver formerly employed. The Author imagines that a wave of condensation is started in the atmosphere each time a beam of light falls upon lamp-black, and a wave of rarefaction is originated when the light is cut off. With reference to the controversy raised by Mr. Preece, at the suggestion of Professor Hughes, that the sounds are due to the expansion and contraction of the air in contact with the disk confined in the cavity, behind the diaphragm, in the experiments with diaphragms, and that the disks do not vibrate at all, the Author thinks his experiments are conclusive in proving that the diaphragm does vibrate.

In his experiments with liquids, the precaution was taken to prevent reflection from the bottom of the test-tube employed, and to slip the flexible rubber tube so far over its mouth as to prevent the possibility of any light reaching the vapour above the surface. Clear water and mercury alone, of the liquids tested, gave no audible sound, the best results being obtained with sulphuric ether and chloride of copper. On the 29th of November, 1880, the Author repeated before Professor Tyndall, at the Royal Institution, the experiments made in Paris, and Professor Tyndall's suggestion that the effects were due to rapid changes of temperature in the body subjected to the action of the beam was proved by a test-tube containing sulphuric ether (a good absorbent of heat) giving a louder sound than another containing bisulphide of carbon (a poor absorbent). These results the Author has since extended; and among a number of vapours, all sonorous, he finds the sounds from iodine and peroxide of nitrogen to be the most intense.

After trying an alloy of selenium and tellurium, in place of selenium in the selenium cell, Mr. Tainter proposed the use of lamp-black, and this has been found most successful. Silver is deposited upon a plate of glass, and a zigzag line is scratched through the film, upon which lamp-black is deposited. When the lamp-black cell is connected with a telephone and galvanic battery, and exposed to the influence of the intermittent beam of sunlight, a loud musical note is produced by the telephone.

The Author and Mr. Tainter have made experiments, not yet completed, upon the sonorous effects produced by different substances. A beam of light, diverging from a focal point, becomes weaker as the distance increases in a calculable degree, and hence the relative sonorous powers of substances emitting sounds of equal intensity can be determined by their distances from the focal point. This has been done for several substances, zinc, hard rubber, and tinfoil diaphragms being found lowest on the scale; silks and worsteds being found higher; the darker colours being the best, and lamp-black the best of all.

The Author next refers to experiments made with the object of discovering the nature of the rays that produce sonorous effects in different substances. He proposes to employ in future the term introduced by M. Mercadier, "radiophones," as a general term signifying an apparatus for the production of sound by any form of radiant energy, limiting the words "thermophone," "photophone," and "actinophone" to apparatus for the production of sound by thermal, luminous, and actinic rays respectively. From the visible spectrum of a beam of sunlight (excepting the extreme half of the violet), as well as in the ultra-red, sounds were obtained from a lamp-black receiver. The loudness increased on moving the receiver gradually from the violet to the ultra-red; the point of maximum sound being far out in the ultra-red; beyond this it decreased and suddenly stopped altogether. Other substances than lamp-black experimented upon produced quite different effects, and the Author concludes that the nature of the rays that produce sonorous effects in different substances depends upon the nature of the substances that are exposed to the beams, and that the sounds are in every case due to those rays of the spectrum that are absorbed by the body.

These experiments have led to the construction of the "spectrophone:" the eye-piece of a spectroscope is removed, and sensitive substances are placed in the focal point of the instrument behind an opaque diaphragm containing a slit, these substances being put in communication with the ear by means of a hearing tube. If the interior of the spectrophonic receiver is smoked, and the cavity filled with peroxide of nitrogen gas, a combination is formed giving good sounds in all parts of the spectrum except the ultra-violet. When a rapidly-interrupted beam of light is passed through some substance whose absorption-spectrum is to be investigated, bands of sound and silence are observed upon exploring the spectrum, the silent positions corresponding to the absorption-bands. In the invisible portion of the spectrum this method of analysis is invaluable, and a table of results on a large number of substances is given in the Paper, which contains fourteen figures of the different apparatus that have been employed throughout the experiments. The Author recognises the fact that the spectrophone must ever remain a mere adjunct to the spectroscope, but anticipates that it has a wide and independent field of usefulness in the investigation of absorption-spectra in the ultra-red.

E. F. B.

The Construction of Selenium Photophone Receivers.

By E. Mercadier.

(Comptes rendus de l'Académie des Sciences, vol. xcii., p. 789.)

These receivers are formed with two brass bands, 0·1 millimetre thick, 1 centimetre wide, and 1 metre to 5 metres long. These are separated by two bands of parchment paper about 0·15 millimetre thick. The bands are rolled into a spiral as closely as possible, and held in a wooden clamp. The apparatus is then heated on a sand-bath or on a plate of copper, until the selenium melting point is attained, when with a stick of selenium a thin layer of that metalloid is put on. A receiver thus prepared of 7 square centimetres surface, gives, with the oxy-hydrogen light, in a Gower telephone of 235 ohms resistance, sounds that could be heard at 2 or 3 metres distance.

P. H.

On the Causes of Interference with Telephonic Transmission.

By A. Gaiffe.

(Comptes rendus de l'Académie des Sciences, vol. xcii., p. 790.)

From experiments on an artificial line with simple telephones, without connection with any other generator, neither directly nor by induction, the Author is led to the conclusion that mere friction of two wires, or two substances in the circuit, will produce the sounds heard in the telephone, and attributed erroneously to induction. It is, therefore, important that the wire of the telephone lines should be firmly attached to the insulator, the negative evidence of the Author's experiments tending to prove that the sounds are the effect of vibrations determined in the iron by similar causes.

P. H.

On a Barometer Founded on the Equivalence of Heat and Pressure on the Volume of a Gas. By C. DECHARME.

(Comptes rendus de l'Académie des Sciences, 1880, vol. xcii., p. 1191.)

The volume of a gas placed under determinate conditions can be reduced by the same quantity either by increasing the pressure or diminishing the temperature. In the same way the volume may be increased by a diminution of pressure or elevation of temperature. There must therefore be a temperature capable of producing upon a given gaseous mass the same change of volume that a given pressure will produce upon it, and *vice versâ*. It is proposed to formulate and represent graphically this equivalence, in order to make it serve for the determination of the atmospheric pressure, the volume and temperature of the confined gas being known.

If V_0 represents the volume of a gas at the temperature 0 and the pressure H_0, and V the volume at the same temperature and the pressure H, thus, according to Boyle's law—

$$V = V_0 \frac{H_0}{H} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

Again, according to the law of expansion of gases (the pressure remaining constant)—

$$V = V_0 (1 + a\, t) \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

a representing the coefficient of expansion, and t the temperature.

Equating these values of V expresses the fact that pressure and heat successively applied to a gas, bring it to the same volume, *i.e.*,

$$V_0 \frac{H_0}{H} = V_0 (1 + a\, t), \text{ whence } t = \frac{H_0 - H}{H\, a} \quad . \quad (3)$$

Make $V_0 = 1$, the formulas (1) and (3) may be applied to the special cases of atmospheric conditions, that is to pressures varying from 710 millimetres to 790 millimetres, and to temperatures from − 25° C. to + 40° C., between which limits Boyle's law may be considered as rigorously exact, and the coefficient of expansion as constant and equal to 0·00367. Make $H o = 1$ atmosphere = 760 millimetres, and finally, after substitution of V in 3, we obtain—

$$V = \frac{760}{H} \text{ and } t = \frac{V - 1}{a} = \frac{V - 1}{0\cdot00367}.$$

The instrument employed consists simply of a mercury or alcohol thermometer, and an air thermometer for measuring the volumes of the gas corresponding to the observed temperatures. The details of construction are given in the original memoir presented to the academy.

The unit volume V_0 having been experimentally determined, at the normal pressure, the volumes V of the gas at various pressures H, and the equivalent temperatures are calculated by means of the preceding formulas. By this means a numerical table is obtained, which can be represented graphically by means of a curve C_0.

If the temperature remained at 0, the pressure alone affecting the volume of the gas, it would suffice to find the pressure, to read this volume on the air thermometer, and to follow on the diagram the horizontal which bears the number of the observed volume; the point of junction of this horizontal with the curve C_0 belongs to the vertical corresponding to the desired pressure.

But the temperature being generally other than 0, the volumes V' corresponding to the various pressures are obtained by means of the formula $V' = V(1 + a t')$; if $t' = 10$ for instance $V' = V \times 1\cdot0367$, or in other words each value of V of the first table must be multiplied by 1·0367. The temperatures equivalent to the pressures will be calculated by the formulas $t = \frac{V' - 1}{a}$. In this way a curve $C_1\,o$ will be obtained, and other curves in an analogous manner.

To find the pressure, the actual temperature on the ordinary thermometer, and the volume on the air thermometer are observed.

Then taking the diagram, the curve corresponding to the observed temperature is followed until the horizontal line of volumes is reached, the pressure is found on the equivalent vertical line. Thus if $t = 10°$, $V = 1\cdot06$, H will be found to be 743·7 millimetres. For intermediate temperatures, the position of the corresponding lines is easily observed, and the pressure to within one-tenth of a millimetre.

This instrument may be called absolute, as it gives the real pressure without further correction, and if the curves are traced for every 2° on a convenient scale, it becomes an instrument of great precision.

E. F. B.

The Practical Manufacture of Oxygen. By E. GUITTON.

(Resumé de la Société des Ingénieurs Civils, 22 April, 1881.)

M. Guitton states that it has long been known that barytes possessed the power of absorbing oxygen from the atmosphere at a certain temperature, and giving it up again at a higher temperature; but this property of barytes had not been utilised, because the result could only be repeated about ten times with the same material, after which it became inert. A process invented by Messrs. Brins Frères, allows of the use of barytes for an indefinite number of times without the quantity of the gas produced at each operation being diminished. The important points of the process are: 1. The preparation of the air to render it easily decomposable by the barytes. 2. The use of pumps or fans to facilitate the peroxidation of the barytes. 3. The employment of a vacuum, or an exhauster, for the extraction of the oxygen after the peroxidation of the barytes. 4. The use of a special pyrometer for regulating the temperature of the furnace, and to maintain the retorts accurately between two given temperatures, which is an indispensable condition to the uniform production of the oxygen. And 5. The preparation of the barytes itself.

An apparatus has been established at Passy for working the process. The air is first pumped into a vessel, called the decarboniser, containing quick lime for the removal of the carbonic acid; it then passes into a saturator furnished with a water spray, where it attains the required degree of moisture, which has been ascertained by experiment to be that corresponding to 65° by a hygrometer of which the zero indicates absolutely dry air and 100° saturated air; provision is made for passing only a portion of the air through the saturator and afterwards mixing it with the remainder, so as to regulate the degree of moisture to that required.

From the saturator the air is forced through the retorts containing the powdered barytes. These retorts consist of iron tubes 8¼ feet long and 6 inches diameter, placed horizontally in gas-generator furnaces. Self-acting pyrometers are used to admit of the required temperature being maintained. Each pyrometer consists of a steel bar resting on the upper retorts, one extremity being fixed in the furnace and the other actuating a lever to which a damper or plate is fixed for controlling the admission of air to the furnace.

The furnace is heated by carbonic oxide to a temperature of 600° Centigrade (1112° Fahrenheit) for the peroxidation of the barytes, the oxygen of the air, forced in by a pump or fan, is absorbed by the barytes, and the nitrogen escapes by a valve set to a pressure of 1¼ atmosphere. To ascertain when the peroxidation is completed, a lighted coal is held at a test cock on the nitrogen outlet, and if the coal continues to burn it indicates that the oxygen is not being arrested, and the baryta is saturated. The temperature is gradually raised to about 800° Centigrade (1472° Fahrenheit), at which it is stopped by the self-acting pyrometer. The oxygen is then drawn from the barytes by exhaustion and forced into a gasholder, and the barytes is then ready for re-charging. At Passy, with an average of ten charges per day, 40 cubic metres (1412 cubic feet) of oxygen were obtained from 100 kilogrammes (220 lbs.) of barytes used.

The gas obtained gave, on analysis, 95 per cent. of pure oxygen, the remainder being nitrogen, due in all probability to small quantities of air getting in through some defects in the apparatus.

Estimates given show the cost of the oxygen to have been 0·619 franc per cubic metre; but it is also estimated that, with increased production, the cost per cubic metre could be reduced to 0·127 franc; while it is stated that oxygen made from chlorate of potash and binoxide of manganese costs 12 francs per cubic metre, and that theatres now have to pay at the rate of 50 francs per cubic metre for a supply of oxygen.

M. Guitton points out the numerous uses to which the gas may be applied if it can be economically produced; it would be highly valuable to metallurgists, chemists, and others, and he suggests that it would furnish a brilliant and economical light if used with mineral oil, or for burning charcoal sticks; he gives an estimate showing that, assuming oxygen to cost 0·50 franc per cubic metre, by using it with mineral oil the cost for a given light would be about one-third that of Paris gas.

C. G.

Poisoning by Carbonic Vapours and by Coal Gas.

(Dingler's Polytechnisches Journal, part 1, May 1881, p. 199.)

Extensive and careful experiments were lately made by Messrs. R. Biefel and T. Poleck to ascertain the proportion of carbonic oxide, carbonic acid, &c., contained in atmospheric air impregnated with the vapours from the combustion of carbon and from the intermixture of coal gas.

In the analyses made by them the total volume of the gases was measured in a saturated condition. The carbonic acid was determined by the use of a moist potash ball, and the oxygen by a ball of papier-maché saturated with an alkaline solution of pyrogallic acid. The analysis was completed in the eudiometer, and the carbonic oxide determined by combustion with oxygen in conjunction with an explosive oxy-hydrogen mixture.

In the analyses of air impregnated with coal gas the heavy hydro-carbons were absorbed by a ball of coke dipped in Nordhausen acid, while carbonic oxide, hydrogen, and light carburetted hydrogen were subjected to combustion in the eudiometer, sulphuretted hydrogen being determined by titration with iodine.

The following Table shows the results of the experiments with carbonic vapours, these being produced by placing vessels containing ignited charcoal in the experimental chamber:—

TABLE I.

—	1.	2.	3.	4.	5.	6.	7.	8.	9.	Average. Per cent.
Carbonic acid	7·03	6·98	7·41	9·65	5·29	5·05	5·16	..	7·46	6·75
„ oxide	0·18	0·44	0·62	0·56	0·19	0·30	0·16	..	0·26	0·34
Oxygen . .	13·65	13·44	13·32	9·30	14·23	14·23	14·73	..	12·62	13·19
Nitrogen . .	79·14	79·14	78·49	80·49	80·29	80·42	79·95	..	79·66	76·72
Duration of experiment .	H. M. 3 58	M. 50	M. 50	H. M. 1 30	M. 25	H. M. 1 30	H. M. 2 18	M. 6	H. M. 3 35	
Result to animal . . .	Recovered	Dead	Dead	Dead	Dead	Dead	Recovered	Recovered	Recovered	
C.O. in spectrum of blood	..	Present	Present	Present	Present	Present	..	Nil	Present	

From this it appears that the carbonic acid produced is in proportion to the loss of oxygen, and that a variable percentage of carbonic oxide is, in addition, mixed with the atmospheric air. One rabbit (a weak specimen) died when the percentage of carbonic oxide reached 0·19 per cent.; another required 0·3 per cent.

Table II. shows the analyses in the cases of intermixture of coal gas with the atmospheric air, and, on comparing the mixtures that proved fatal to life with those in Table I., the composition of the gases is seen to be very different.

TABLE II.

—	Percentage in relation to Gas used. Experiment 1.	Percentage in relation to Air. Experiment 1.	Percentage in relation to Gas used. Experiment 2.	Percentage in relation to Air. Experiment 2.	
				a.	*b.*
Carbonic acid . .	2·78	0·04	2·12	0·08	0·18
Heavy hydrocarbons	4·56	0·04	4·85	0·35	1·16
Marsh gas . . .	32·00	0·04	30·80	2·36	3·17
Hydrogen . . .	49·07	0·04	53·13	4·42	3·54
Carbonic oxide . .	4·70	0·20	6·75	1·48	0·53
Oxygen	0·43	20·75	0·42	19·15	18·11
Nitrogen . . .	6·46	78·97	1·93	72·16	73·31
Duration of experiment	..	H. M. 2 12	..	H. 2	H. M. 5 5
Result to animal .	..	Appearance of death	..	Died	Died
C.O. in blood spectrum	..	Present	..	Present	Present
Remarks . . .	..	..	..	Air explosive	Air explosive

In these cases the air does not become poor in oxygen by the introduction of the gas, but the normal proportion of oxygen to nitrogen is maintained, for the constitution of the air is not altered by any chemical process, but by the introduction of new elements and the displacement by them of the atmospheric constituents. The carbonic acid increases to 0·5 per cent. before the mixture becomes fatal to life. The limits within which carbonic oxide can be breathed before death ensues appear to be greater in the case of poisoning by coal gas than with charcoal vapours. Evidently a greater quantity of carbonic oxide may be breathed before the effect is fatal when the air maintains its normal proportions than when the oxygen becomes reduced to two-thirds or one-half its normal quantity.

Table III., in which the air is contaminated by the introduction of pure carbonic oxide, gives a further insight into the part played by this gas in regard to toxological effect.

Table III.

Composition of the Air and Gas Mixed	1.	2.	3.	4.	5.
Carbonic oxide . . .	0·04	1·94	1·53	1·65	0·02
„ acid . . .	0·04	0·27	0·61	0·54	0·74
Oxygen	..	20·50	20·52	20·50	20·60
Nitrogen	..	77·29	77·34	77·31	77·64
Duration of experiment .	20 hours	1 hour	52 min.	25 min.	10 min.
C.O. in blood spectrum .	Nil	Present	Present	Present	Present
Result to animal . . .	Recovered	Dead	Dead	Dead	Recovered

With the admixture of pure carbonic oxide as much as 1·02 per cent. can be breathed for a short period without fatal results.

Experiments with pure carbonic acid showed that when the percentage was 6·7 the animal became exhausted, but rapidly recovered on exposure to fresh air, and death did not ensue until the mixture contained 50·4 per cent. of this gas.

The fatal effect of sulphuretted hydrogen is important, having regard to its presence in coal gas and in the gases evolved from mines and sewers. With the presence of 0·05 and 0·037 per cent. of this gas death followed after one hour and fifty-eight minutes, and the diagnosis differed considerably from that exhibited in the case of poisoning by carbonic oxide. In a further experiment carbonic oxide and sulphuretted oxide were mixed in varying proportions, and the result showed that the same small proportion of sulphuretted hydrogen rendered fatal the process of poisoning by carbonic oxide.

In Breslau, during the preceding winter, several cases of poisoning by coal gas which had escaped from the street mains having occurred, in some of which instances no smell of gas was detected, experiments were made to ascertain what change, if any, occurred in the constitution of coal gas after passing through a considerable stratum of earth. A 2-inch pipe about 7 feet long was filled with humid earth and gas passed slowly through it. When the gas issued from the pipe it had almost entirely lost its characteristic smell. The following are the analyses of the gas before and after passing through the earth:—

Constituents.	Coal Gas.	After passing through Earth.
	Per cent.	Per cent.
Carbonic acid	3·06	2·23
Heavy hydrocarbons . .	4·66	0·69
Marsh gas	31·24	17·76
Hydrogen	49·44	47·13
Carbonic oxide	10·52	13·93
Oxygen	0·00	6·55
Nitrogen	1·08	11·71

In comparing these it is seen that about 75 per cent. of the heavy hydrocarbons, and with these the hydrocarbon vapours and particles of tar held in suspension, were condensed and absorbed by the earth. The light carburetted hydrogen was reduced nearly 50 per cent., while the hydrogen remained almost unaltered, and the carbonic oxide appeared to be increased about 25 per cent. It is also worthy of remark that the oxygen and the nitrogen resulting from the air that became mixed with the gas do not bear their normal relative proportions.

The chief danger arising from the leakage of gas from street mains consists in the non-absorption of the carbonic oxide by the earth, but the removal of the hydrocarbons which give the gas its characteristic smell.

In 1872 Pettenkofer reported a case of two persons who fell ill from inhaling air contaminated by coal gas, and who remained four to six days in the dwelling before the escape of gas was perceived. Biefel observed an analogous case in the winter of 1875. The gas escaped from a broken main into a bedchamber, the occupant of which was afflicted by dizziness and headache on awaking, but the smell of gas was not perceptible until a later period. In the winter of 1879–80 frequent cases of poisoning by gas occurred in Breslau. During six weeks of the severest cold ten cases of illness and one death were caused by leakage of gas from broken mains. In the fatal case death ensued after two days' illness, and was followed by the family of the deceased being found unconscious in their beds without the escape of gas being perceived. A spectroscopic analysis of the blood of the patients and of the deceased revealed the presence of carbonic oxide, and, on search being made, gas was discovered making its way through the joints of the floor-boards in the room where they had slept.

In another case of leakage in which the gas got into a drain and thence into a dwelling-house a sample of the gas was collected. It possessed hardly any smell and burned with a blue flame, and the analysis gave the following proportions:—

Heavy hydrocarbons	1·13
Marsh gas	12·47
Hydrogen	14·90
Carbonic oxide	0·82
„ acid	3·51
Oxygen	6·74
Nitrogen	60·42

The carbonic oxide present was more than sufficient to produce symptoms of poisoning.

If the combustible gases be deducted the constitution of the air in the drain will be found to be as follows:—

Carbonic acid	4·96
Oxygen	9·54
Nitrogen	85·50
Total	100·00

G. E. S.

The Joining of Substances by Pressure. By WALTHÈRE SPRING.

(Revue universelle des Mines, 1880, vol. viii., pp. 470–515.)

In experiments made two years ago, with a pressure estimated at 20,000 atmospheres, the Author, who is professor in the university of Liége, compressed from the state of powder nitrate of potash and also nitrate of soda into small hard blocks, which were more solid than if made by fusion; they were translucent like porcelain, and the original separate particles composing them could not be traced. But poplar saw-dust, pulverised sandstone, and chalk, though formed into equally hard blocks, had their particles imperfectly united, and broke along surfaces of contact of the original grains, not through the grains themselves. The possibility being thus proved of uniting solids by pressure, it remained to extend the experiments over a larger number of substances, to make trials in a vacuum, and to ascertain what effect temperature had upon the readiness with which the union could be produced.

Of these further experiments an account is now given, prefaced by a critical review of previous investigations, which have served as a starting point for the Author's. Faraday's discovery in 1850 of regelation, applied to glaciers by Tyndall,—and their experiments, together with those of Tresca, Helmholtz, and Bottomley—gave rise to various explanations and theories, which are examined at considerable length in connection with these names, as well as with those of Forbes, James Thomson, Clausius, Bunsen, Sir William Thomson, Mousson, Pfaundler, Rühlmann, Schultz, and Jungk. Eighty-three different substances were experimented upon by the Author, comprising metals, metalloids, oxides and sulphides, salts, carbon compounds, and mixtures of chemical re-agents. The whole of these experiments are severally described in detail.

Compressing Apparatus.—In his preliminary experiments the Author had effected the desired compression under a ram in a steel cylinder, by means of a screw and a hand-lever 5 feet long; but the solid blocks so compressed were very difficult to get out whole, and the real pressure put upon them could only be roughly guessed, and trials could not be made in a vacuum. In the later experiments therefore a lever press loaded by a dead weight was substituted, of which a detailed description and drawing are given. The cast-steel die or cylinder in which the blocks were compressed was 1½ inch diameter outside, ⅓ inch inside, and 2 inches high; it was divided longitudinally down its centre, the halves being held tight together by a nut at top, and at bottom by fitting into a recessed base-plate; they could thus be separated for getting the compressed block out without injuring it. The die was covered by a gun-metal bell or air-tight receiver, from which the air was exhausted for experimenting in a vacuum; the ram, loaded by the lever, passed down into the cylinder through a stuffing-box in the top of the bell. The pressure exerted however could not be increased beyond 10,000 atm.; for the steel ram itself crushed at that limit, and had to be replaced after each operation. On this account, and as it was found that the presence of air in the experiments had scarcely any perceptible effect, while there were also practical difficulties in the way of experimenting at high temperatures with this apparatus, the Author ultimately reverted to the previous principle of a screw press, having a screw of ⅛ inch pitch, worked as before by a hand-lever 5 feet long. The cast-steel die or cylinder, of ⅓ inch diameter inside, is here again divided longitudinally down the centre into halves, of which the facing edges are checked into each other with the view of preventing leakage under the heaviest pressure that can be exerted of 20,000 atm. The die is inserted within a slot, shaped to fit it, in a strong cast-steel chase or rectangular frame (of which a drawing is given), tapped at the upper end for the pressing screw to work through, and at the lower for a screwed plug, which closes the bottom of the die and serves for inserting the substance to be compressed. Two clamps, encircling the chase transversely, lock the halves of the die fast together by means of tightening screws. For experimenting hot, the die having first been filled cold, the apparatus is held upright between wood chocks in a vice, and heated by a spirit lamp below; the pressure is applied as soon as a scrap of tin, bismuth, lead, or zinc, &c., melts on the top of the die, which by that time has accordingly attained the corresponding temperature. Heating was not tried for substances that gave good results without it; on several its effect was found to be less than might have been supposed.

Metals.—Of the eight metals tried by the Author, all except zinc were compressed only at a temperature of 14° C. or 57° F. From lead filings, compressed in a vacuum under about 2,000 atm., a block was obtained as solid as if cast by melting, and the microscope failed to detect the slightest trace of the original constituent particles. At 5,000 atm. the lead would no longer stand under the ram, but oozed out through all the joints like a liquid, allowing the ram to be driven down to the very bottom of the die. On opening the die, the fine flakes of lead-leaf had exactly the appearance of sheet lead produced by rolling: conformably with the results of M. Tresca's experiments on the flow of solids.[1] The specific gravity of the compressed lead was found to be 11·5 instead of 11·3. Bismuth, though so brittle and easily pulverised, yet joins again readily under pressure: a block compressed from fine powder under 6,000 atm.[2] breaks with a crystalline fracture just as though it had been cast; and the same holds true for almost all the other substances tried. Tin filings join perfectly under 3,000 atm.; at 5,000 the tin begins to flow out through the joints of the die, but soon stops; at 5,500 begins again, and again stops; and so on up to 7,500 atm., under which pressure the flow becomes continuous. Zinc filings join perfectly under 5,000 atm., and under 7,000 the compressed block barely begins to flow.

Joining less readily than the other metals already cited, zinc forms a good illustration of what takes place also in the compression of all the other substances tried, proving that union depends solely on the closeness with which the particles are brought into contact. Under no more than 260 atm. pressure, zinc filings do not join. Under 700 they so far join as to come out of the die in a block, which however breaks very easily and then falls to dust; a microscope shows distinct spaces between the filings in the block. Compressed under 2,000 atm. the block will hold together under the file, but breaks under the hammer; its fracture still shows spaces between some of the filings, though much fewer; whilst others of the particles are now clearly seen to have become perfectly joined. With 4,000 atm. very few interstices can be detected; and with 5,000 the block is perfectly solid throughout, and stands gripping in a vice and filing and hammering like a block cast by melting. A trial was also made of compressing pulverised zinc at the temperature at which it is most malleable, namely about 130° C. or 266° F.; it then joins still better, and the block breaks with a crystalline fracture.

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[1] *Vide* Proceedings Institution of Mechanical Engineers, 1867, p. 114; and 1878, p. 301.

[2] From the context in the original this is probably a misprint for 3,000 atm. (or less).—A. B.

Aluminium joins too weakly under 4,000 atm. to stand filing; under 5,000 it stands filing, but not hammering; while with 6,000 it joins perfectly and becomes malleable. The same holds good with regard to copper. In the case of antimony, the trial was not made with filings, but with the finest powder possible, in order to ascertain what pressure would reproduce the metallic lustre which is lost in the state of powder. With 5,000 atm. the lustre reappeared on the surface of the compressed block, but its centre remained pulverulent and dull grey; under higher pressures the lustre penetrated deeper and deeper in from the surface. Spongy platinum begins to join under 5,000 atm., with metallic lustre on the surface; but the block is friable and the fracture dull, and higher pressures do not produce so perfect a union as in the preceding instances. The readiness with which these metals join is seen to be inversely as their hardness; and as the hardness generally diminishes with rise of temperature, it may be concluded that the softer a metal becomes by heating, the more readily will it weld: just as iron gets very soft before melting, and welds easily.

Metalloids.—Among the six metalloids experimented upon, sulphur was compressed in its three several allotropic states—prismatic, plastic, and octahedral (native): the specific gravities of the first and third being respectively 1·96 and 2·05, and their melting points 120° C. and 111° to 114° C. respectively, or 248° F. and 232° to 237° F. Compressed with 5,000 atm. the block made from prismatic sulphur showed an octahedral fracture when broken while its melting point was 115° C. or 239° F., and its specific gravity 2·02; these three conditions concurrently point to a change from the prismatic to the octahedral state as the effect of pressure. Under 6,000 atm. plastic sulphur became similarly transformed into octahedral: confirming the conclusion that the nature of the allotropic condition assumed by the compressed substance corresponds with its density. Octahedral sulphur itself joins with great readiness, forming sound blocks under 3,000 atm. Amorphous carbon (charcoal), obtained by calcining sugar in a muffle, would not join at all under the very heaviest pressure; it appears extremely elastic, regaining its original bulk on the removal of the pressure.

Oxides, Sulphides, Salts.—Among the ten oxides and sulphides, and the thirty-two salts &c., of which the trials are next detailed, crystallised sulphate of copper (blue vitriol), almost white as a fine powder, gradually regains under compression its deep blue colour. Beginning to join at 3,000 atm., the mass is then blue only at its edges; at 4,000 it is blue throughout, but paler than its proper crystals; while at 6,000 the full blue is recovered, and the block is transparent, and harder than a crystal.

Carbon Compounds.—Nineteen of these were experimented upon. Paraffin, though apparently softer than wax because easier to cut, is found to stand compression better, flowing only under 2,000 atm., whilst wax runs like water at 700; the compressed blocks of paraffin are more transparent than those cast by melting. Coal, whether bituminous or non-bituminous, consolidates from fine powder under 6,000 atm. into a shiny block, which under that pressure can be moulded with the greatest ease; this may serve to explain how seams of a substance ordinarily so brittle can have assumed the contortions that are met with in coal mining. Brownish peat is compressed by 6,000 atm. into a hard black shiny block, which looks so exactly like coal as to have been taken for it by all to whom it was shown; when broken at the edges it discloses the same laminated appearance as coal, and its original vegetable texture has entirely vanished; it makes a compact coke of dull grey hue, just like that obtained from coal. In the opinion of M. Frémy the primeval vegetation which has now become coal would first be converted into peat by fermentation under water—a process which would take place without any great rise of temperature; and from the Author's experiments, the peat would then become converted into coal by the action of pressure again without requiring a rise of temperature.

Chemical Combinations.—Five mixtures were tried of substances which in combining undergo diminution of volume. Copper filings being mixed cold with coarsely powdered sulphur, no chemical action takes place between them at atmospheric pressure; but under 5,000 atm. pressure they combine perfectly, forming black crystallised sulphide of copper (Cu_2 S, grey copper ore), in which not the slightest trace of metallic copper can be detected; the contraction in combining is from 138 volumes of the mixture to 100 volumes of the chemical compound. Two experiments on mixtures that expand in combining agreed with those of Cailletet and Pfaff, showing that chemical combination in such cases is prevented by pressure; but in a third the affinities were strong enough for combination to take place in spite of the pressure exerted.

General Conclusions.—From the Author's experiments solid substances appear to possess the property of joining when in close contact; and they join the more or less readily according as they are softer or harder. The property seems however to depend also on whether they are of crystalline structure or are essentially amorphous. The crystalline substances that have been tried have without exception exhibited this property; and even a substance accidentally amorphous showed a crystalline fracture after compression. Probably therefore softness conduces to joining, only because it favours perfect contact of the solid particles under compression, and does not prevent the molecules from arranging themselves in the direction of the axes of crystallisation. On the other hand, among properly amorphous substances are some, like wax, which join very easily, and others, like charcoal, which will not join. Furthermore, where compression changes a substance from one allotropic condition to another, or from an amorphous to a crystalline structure, the change is always that corresponding with the increased density or higher specific gravity. Hence the Author's general conclusion is that, apart from either addition or subtraction of heat, substances assume under compression by external force the state of aggregation or consolidation which suits the volume they are compelled to occupy.

A. B.

Ventilation of Halls of Audience. By Rob. Briggs, M. Inst. C.E.

(Trans. Amer. Soc. C.E., vol. x., 1881, p. 53.)

In this Paper careful investigation as to the amount of air requisite for the ventilation of halls of audience is considered.

The Author also explains that, notwithstanding the direction given to the breath when breathing from the nostrils, the columns of breath ascend in all places where the temperature of air is below 85° Fahrenheit, and that by direct experiments it has been proved that though carbonic acid can be poured from one vessel to another like water, for all that it diffuses itself very rapidly, and then there will be no less carbonic acid at the top of a tube 100 feet high than at the bottom.

The Author considers that with a cubical capacity of 1,000 feet per person for a room continually occupied, 30 cubic feet per minute per person will afford pleasant and satisfactory ventilation.

Increase the temperature and humidity for degrees and percentages above 70° and 70 per cent., even 60 cubic feet per person per minute is not excessive quantity of air, where 30 is named above.

Finally the Author states the exact quantity of fresh air supplied to each person of an audience per minute must be taken to have an arbitrary value, founded on economic and structional as well as upon medical and chemical considerations.

Except in very cold weather crowded halls of audience do not require any heat, but the Author considers that all the corridors, passages, and especially the auditoriums of theatres, should be warmed to a comfortable temperature before the audience collects.

The problem, however, is how to introduce and distribute cold currents of air amongst a crowded audience. The feeling of cold air from currents of air proceeds from two sources: 1st, the abstraction of heat in warming the air itself; and 2nd, the absorption of vapour by the air, which vapour will have been formed at the expenditure of heat from the natural moisture of the skin.

Thus air, at 35° Fahrenheit and 70 per cent. of humidity, demands nearly the same quantity of heat to warm it to 70° that is requisite to vapourise the moisture which raise the humidity to 75 per cent. at 70° Fahrenheit.

The Author then considers the systematic supply of air, velocity of the currents in ducts and flues, and the dimensions of same, and the directions these currents of air should take in a crowd or an audience.

The ventilation of gas burners, and suggestions on the use of electric lighting for halls of audiences are also considered, and the different methods in use for producing the movement of the air; and at the same time the Author calls particular attention to the Washington type of fan, used when forced ventilation is adopted.

The American heating by steam is also described from its origin in 1840 to the present time, with estimation of the sizes of the main pipes and their branches.

The different type of boilers in use, with the dimensions of grate surface, area, and heights of chimney shafts, is also noted.

Indirect and direct radiating surfaces for warming spaces are discussed and fully worked out, and methods of regulating and controlling the different sections of an application.

Finally the Author, in the conclusive remarks of this Paper, notes that it becomes the indispensable preliminary that the original planning and subsequent erection of the building shall provide suitable rooms for apparatus, together with ducts, distributing passages, and flues.

An addendum is added to the Paper, with data relative to the form and construction of fans, and also estimation of heating power for rooms with different exposures to the external air.

W. W. P.

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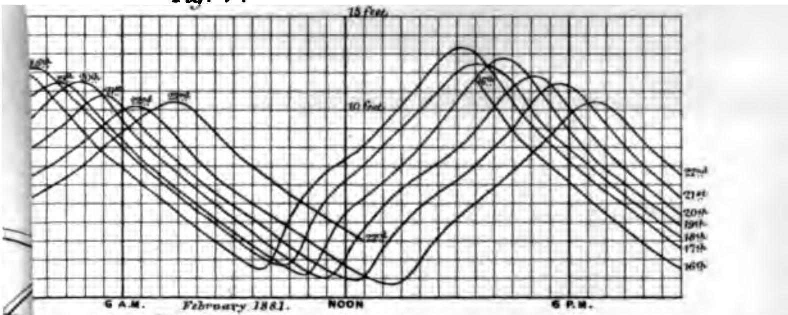

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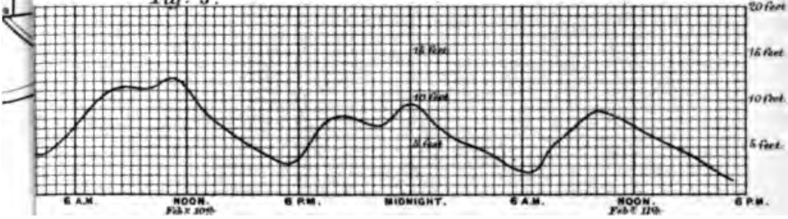

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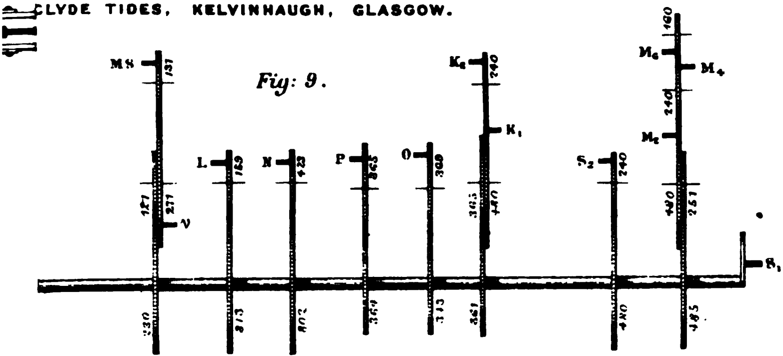
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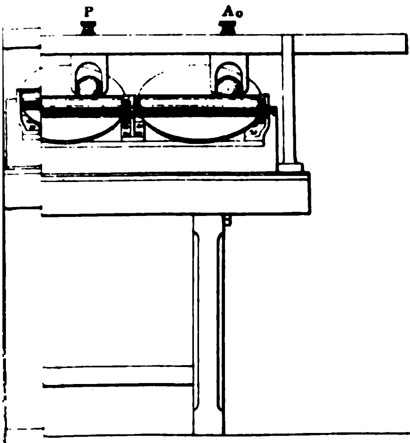

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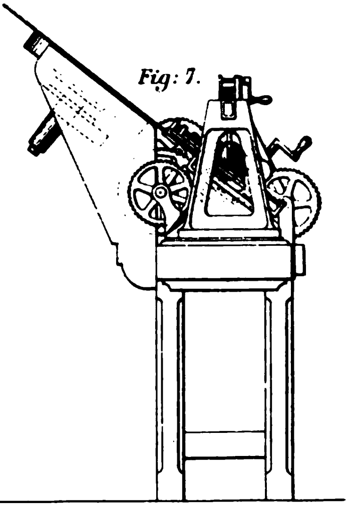

THOs KELL & SON, LITH 40 KING St COVENT GARDEN

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PLATE. 1.

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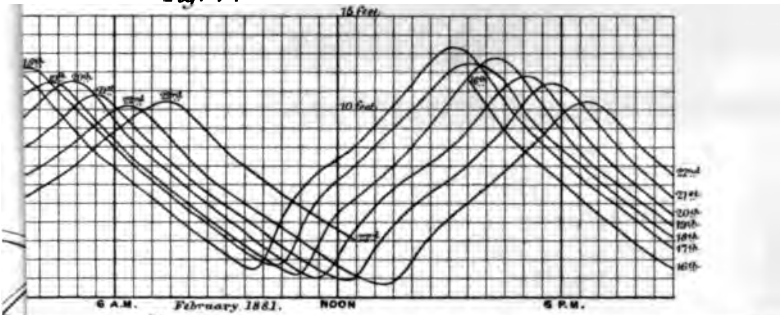

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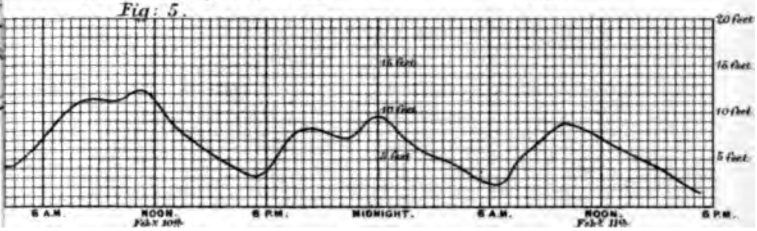

CLYDE TIDES, KELVINHAUGH, GLASGOW.

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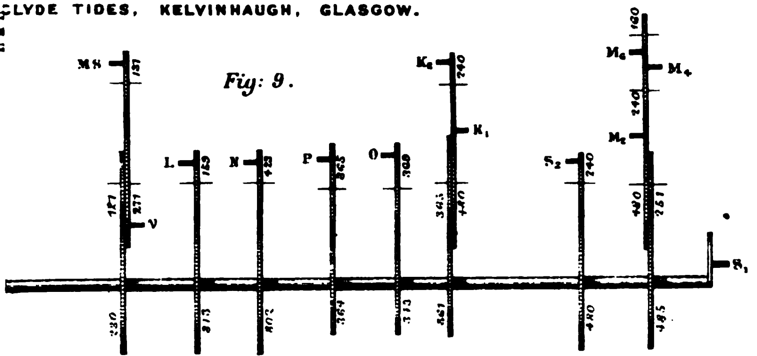

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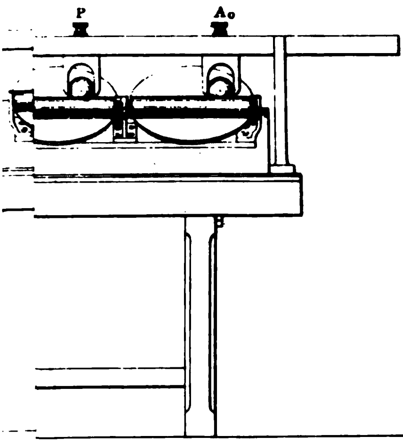
OF GEARING OF TIDE PREDICTER.



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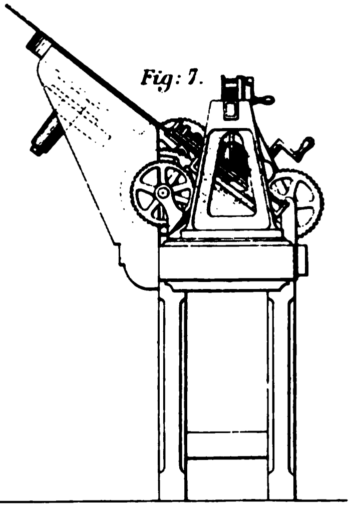

THOS KELL & SON. LITH 40 KING ST COVENT GARDEN.

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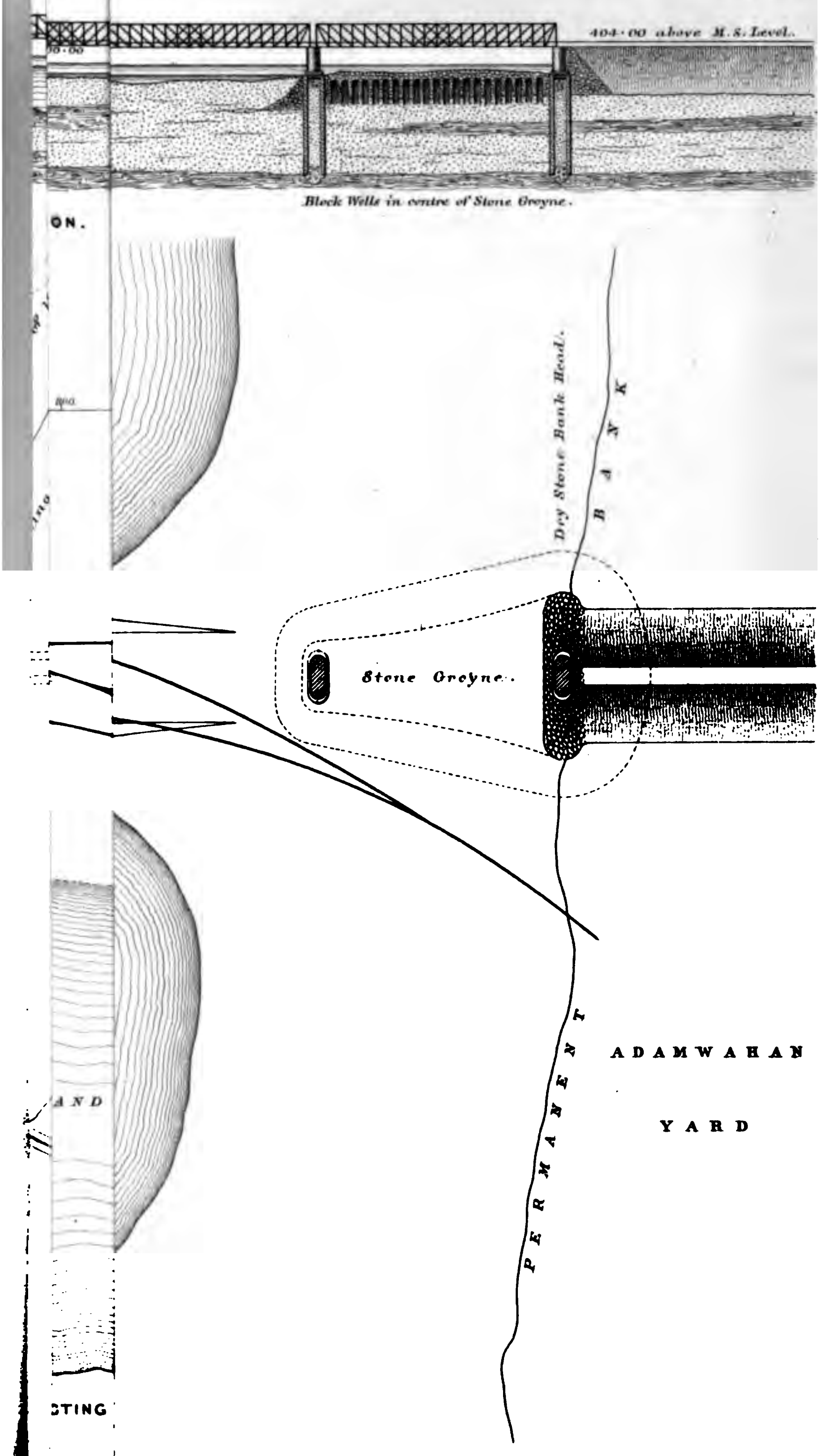
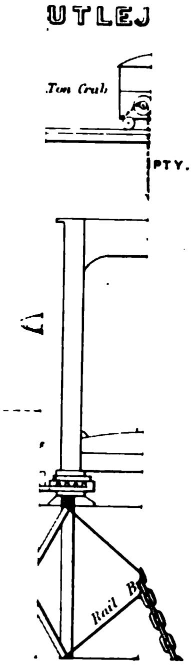

404·00 above M.S. Level.
Block Wells in centre of Stone Groyne.
ON.
Dry Stone Bank Head.
BANK
Stone Groyne.
PERMANENT
ADAMWAHAN
YARD
AND
STING

. Vol. I.

THOS KELL & SON, LITH. 40 KING ST COVENT GARDEN.

PLATE.3.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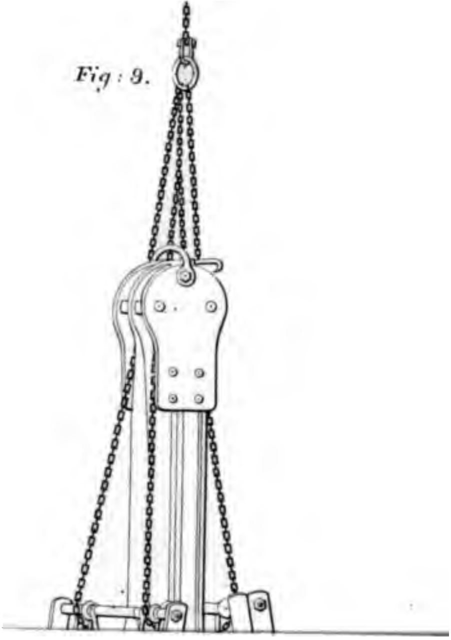

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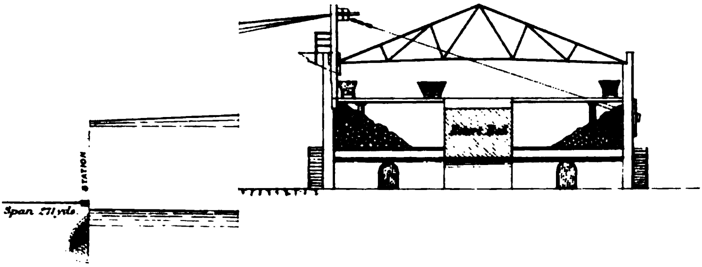
THOS KELL & SON, LITH. 40 KING St COVENT GARDEN.

PLATE 4.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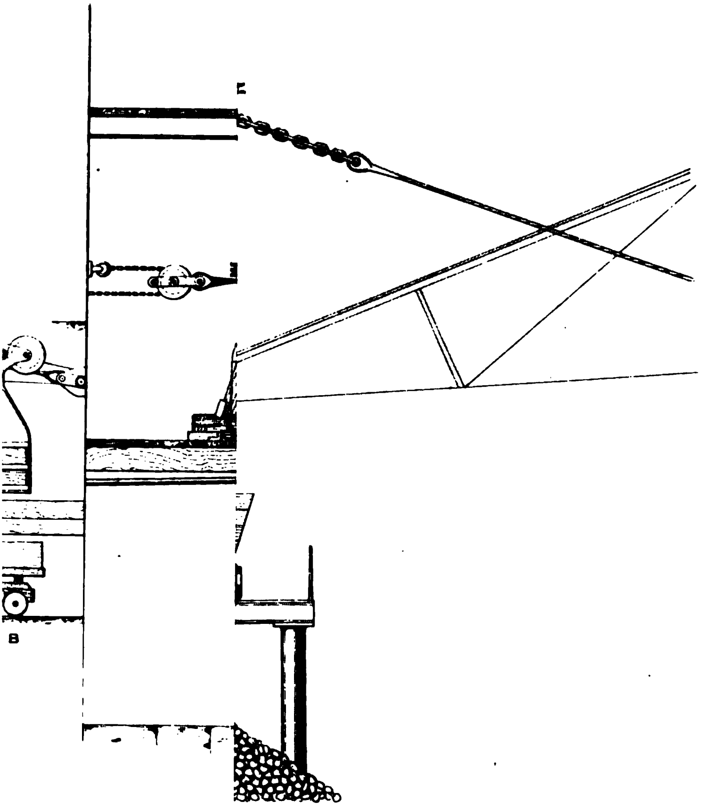

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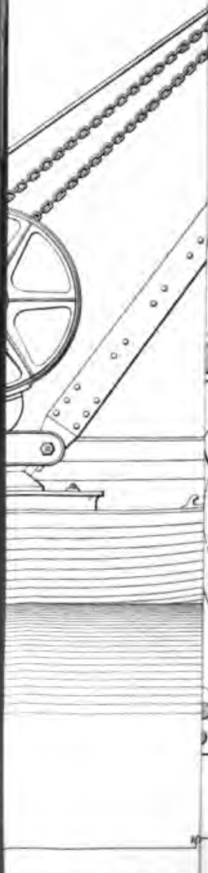

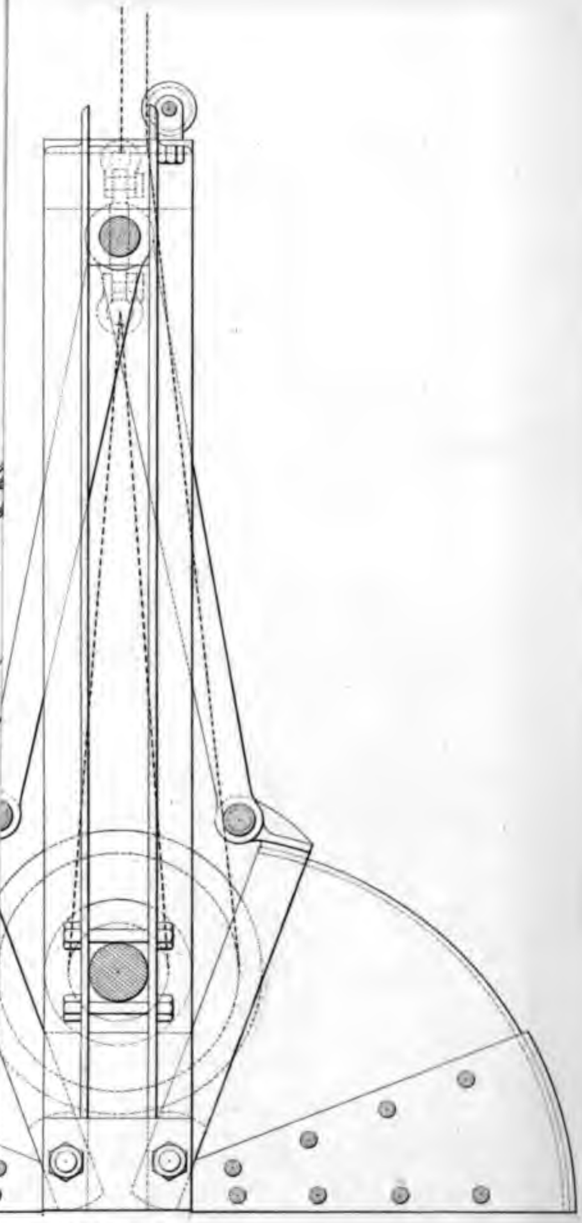

BUCKET OPEN.

Scale. 1 Inch to a Foot.

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THOS KELL & SON, LITH. 40 KING ST COVENT GARDEN.

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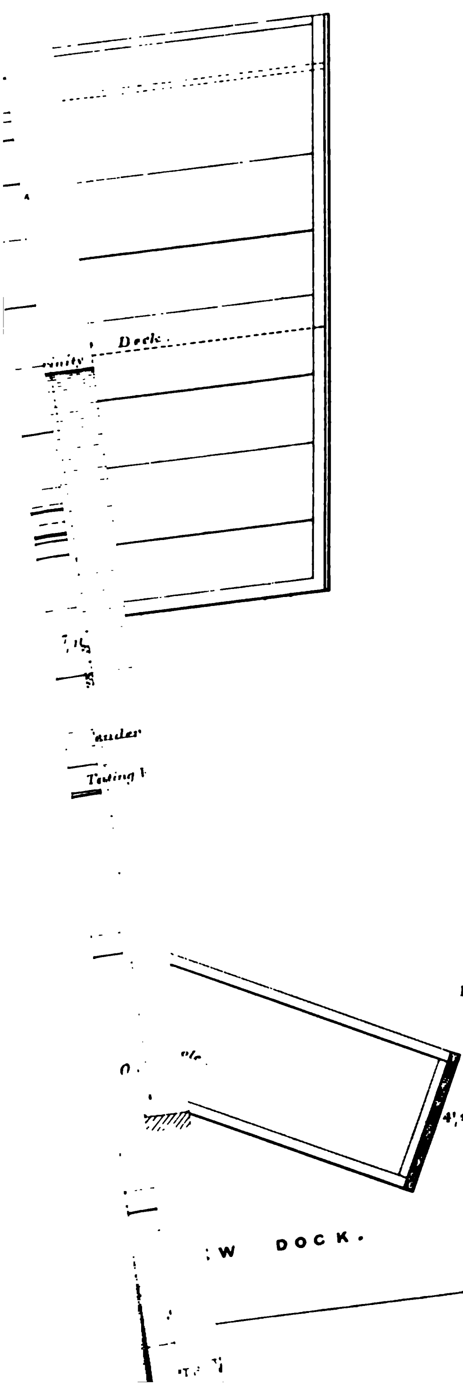
Deck.
rinity
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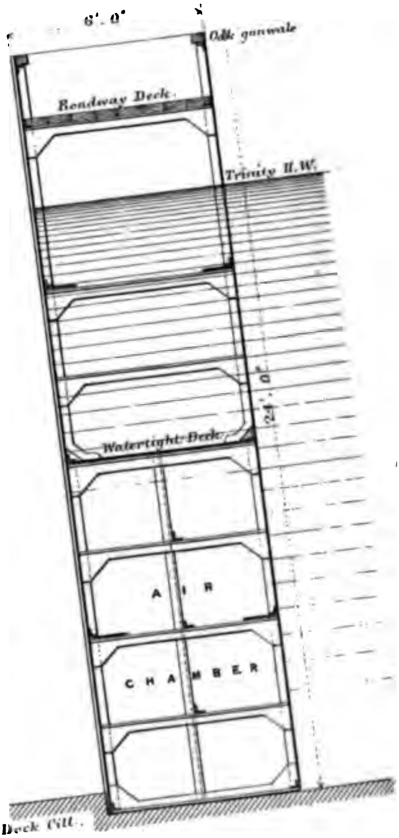
ole.
4½' Teak Abutment Fenders

Fig: 6.


6'. 0"
Oak gunwale
Roadway Deck.
Trinity H.W.
24'. 0"
Watertight Deck.
AIR
CHAMBER
Deck Cill.

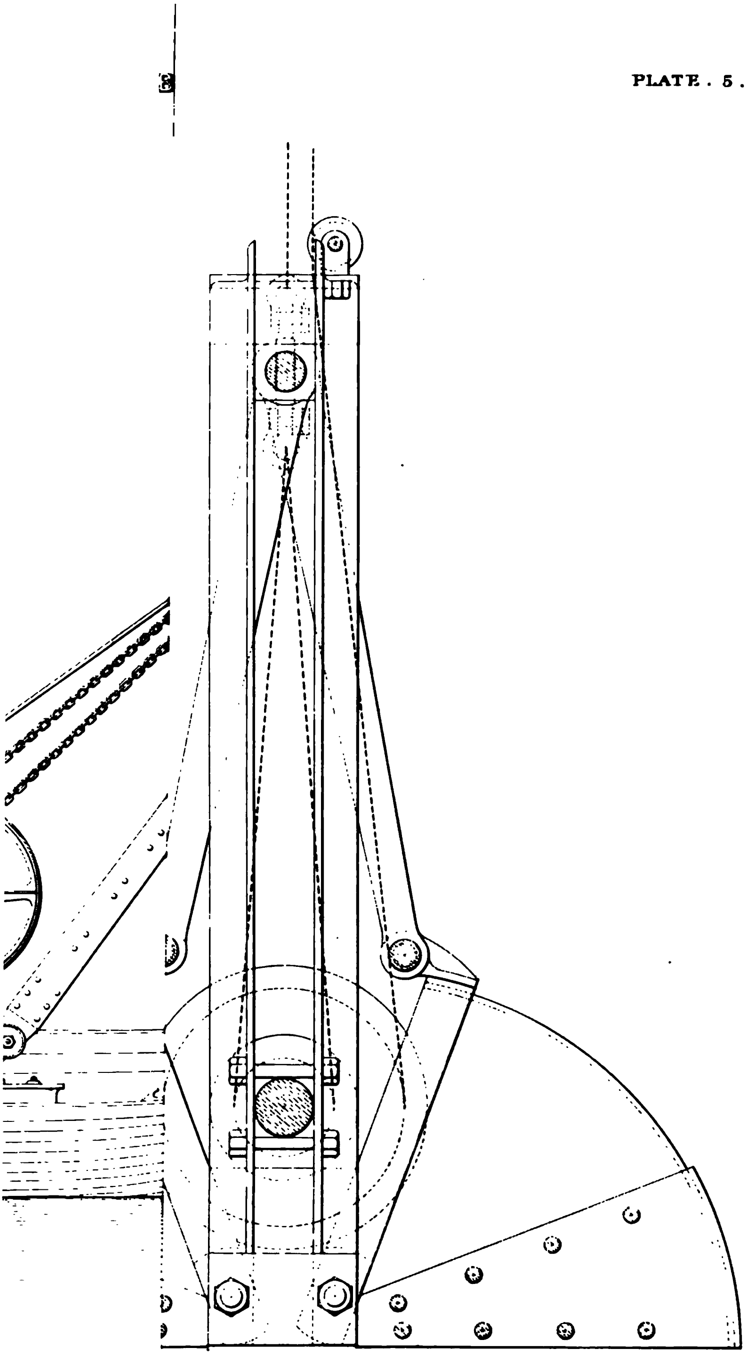
CROSS SECTION.

W DOCK.

30 Feet.

THOS KELL & SON. LITH 40, KING ST COVENT GA

PLATE . 5.



BUCKET OPEN.

Scale . 1 Inch to a Foot .

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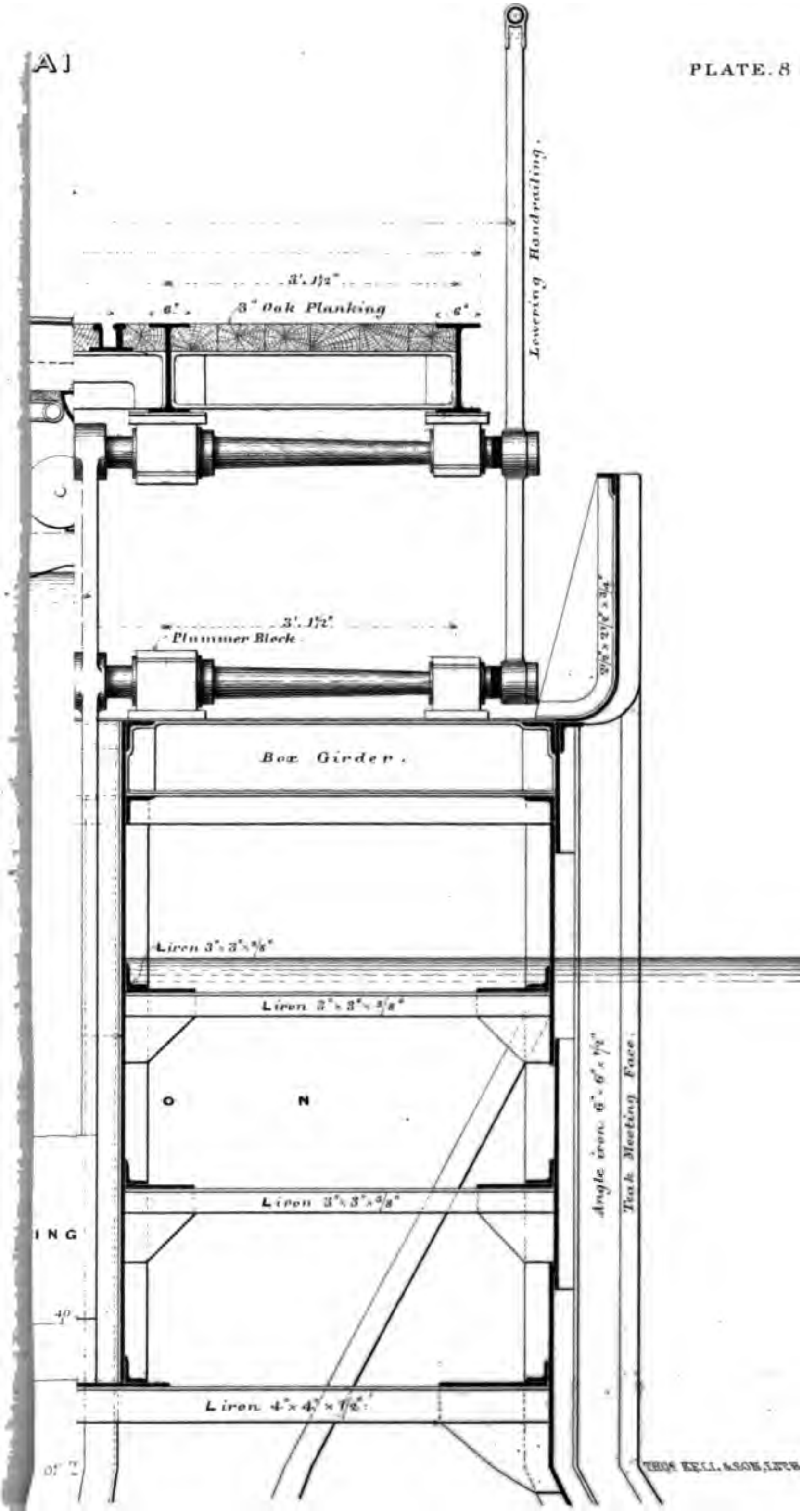
THOS KELL & SON LITH. 40 KING ST COVENT GARDEN

PLATE. 8


A]
Lowering Handrailing.
3'. 1½"
6"
3" Oak Planking
6"
3'. 1½"
Plummer Block
2½" × 2½" × ¾"
Box Girder.
L iron 3" × 3" × ⅝"
L iron 3" × 3" × ⅝"
O
N
L iron 3" × 3" × ⅝"
ING
Angle iron 6" × 6" × ½"
Teak Meeting Face.
40
L iron 4" × 4" × ½"

THOS KELL & SON, LITH